

# THE 20<sup>TH</sup> INTERNATIONAL CDIO CONFERENCE, TUNISIA

## Proceeding - Full Papers

Lamjed Bettaieb, Nadia Ajailia, Jens Bennedsen, Kristina Edström,  
Mark Nivan Singh, Reidar Lyng, Nicoleta Maynard, Johan Malmqvist, Fredrik Byström (eds.)





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# Editorial

The CDIO Initiative is an approach to designing innovative educational frameworks, aiming for educations that support students in developing the necessary professional skills required of a practicing engineer while simultaneously acquiring strong technical fundamentals. This is done by providing students with dual-impact learning experiences that are based upon the lifecycle of an engineering project, the Conceiving-Designing-Implementing-Operating (CDIO) of real-world products, processes, and systems. Throughout the world, over 200 institutions have adopted CDIO as the framework for curriculum development.

CDIO collaborators recognize that engineering education is acquired through programs of varying lengths and stages in a variety of institutions and that educators in all parts of this spectrum can learn from practice elsewhere. Several times each year, CDIO collaborating institutions, engineering educators and researchers gather to exchange ideas and experiences, review developments, assess and further refine the CDIO approach.

The Annual International Conference is the key event for the CDIO community where CDIO practitioners from all over the world come together, share knowledge and promote the advancement of the practice of the CDIO Initiative for producing the next generation of engineers. It includes presentations of papers as well as specialized seminars, workshops, roundtables, events, and activities.

The 20<sup>th</sup> CDIO International Conference took place in Tunis, Tunisia, June 10-13, 2024, hosted by Ecole Supérieure Privée d'Ingénierie et de Technologies (ESPRIT).

The main theme of the conference was **“Engineering education in the era of AI”**. The theme is present in the keynote presentations, paper presentations, roundtables, workshops, working group sessions, and the panel debate on the final day of the conference. The program covered many aspects of engineering education, such as AI driven learning approaches, sustainability, active and adaptive learning, lifelong learning and change leadership. Specific topics covered include curriculum agility, emotion and reason in engineering education, digital transformations and of course reports on implementation of the CDIO Standards and the CDIO Syllabus.

The conference featured three types of contributions: Full Papers, Project in Progress contributions, and Extended Abstracts for Activities. All contributions have undergone a full single-blind peer-review process to meet high scholarly standards. The Full Papers are papers assessed to be of archival quality and thus published in these proceedings. They fall into three tracks: Advances in CDIO, CDIO Implementation, and Engineering Education Research. The Projects in Progress contributions describe current activities and initial developments that have not yet reached completion at the time of writing. The Extended Abstracts summarize the Roundtable Discussions, Workshops and Working groups held at the event.

Initially, 206 abstracts were submitted to the conference. The authors of the accepted Full Paper and Projects in Progress abstracts submitted 161 manuscripts to the peer review process. During the review, 313 review reports were filed by 98 members of the 2024 International Program Committee. Acceptance decisions were made based on these reviews. The reviewers' constructive remarks served as valuable support to the authors of the accepted full papers when they prepared the final versions of their contributions. We want to address our warmest thanks to those who participated in the rigorous review process.

A total of 61 educational institutions from 30 countries, representing 6 continents, were present during the conference. The total number of registered participants at the conference was 194.

This publication, which is available as an electronic publication only, contains the 62 accepted Full Papers that were presented at the conference, of which 1 is in the Track Advances in CDIO; 51 are in CDIO Implementation; and 10 are in Engineering Education Research. These papers have been written by 297 different authors with submitting authors from 24 different countries. Additionally, 36 CDIO Project in Progress contributions were presented at the conference but are not included in this publication. Also, a total of 26 collaborative contributions for activities in 11 Workshops, 11 Roundtable Discussions and 4 Working Groups took place, as well as a range of social events.

Note that the Proceedings of the International CDIO Conference Proceedings is SCOPUS Indexed.

We hope that you find these contributions valuable in developing your own research, curriculum development, and teaching practice, ultimately furthering the engineering profession. We also hope that you benefit through the truly unique community of practice that exists within the CDIO Initiative.

The CDIO 2024 Program Committee wishes all of you a wonderful CDIO experience!

Tunis, June 10, 2024.

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# **I ADVANCES IN CDIO**

# **CURRENT AND FUTURE VALUE OF BEING IN CDIO – CDIO COMMUNITY IDEAS**

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## **ABSTRACT**

CDIO started as a project in 2000 and in 2004 CDIO initiative was formed as a worldwide collaboration in engineering education. The collaboration is built on professional networking, shared knowledge, and practices. Its members come from all over the world and share a common goal of enhancing teaching and learning in higher education. As the community grows, it is essential that we understand the expectations of the CDIO community so that the CDIO initiative, framework, community etc. can be enabled to keep itself interesting and valuable. This paper reports on a series of engagements with CDIO collaborators at the CDIO International Conference, International Working Meetings and Regional meetings that explored the rationale of working with CDIO, how we can improve the CDIO initiative, and how to keep it valuable for our collaborators. It reflects the value of being in CDIO from the viewpoint of current and potential CDIO collaborators. There is broad consensus amongst the members that CDIO provides a valuable framework for enhancing the quality of engineering education; opportunities to share, learn and benchmark their curriculum; and network with an international community of educators with similar challenges and goals. As the landscape of higher education continues to evolve, members recognize the importance of CDIO keeping up to date with changes in the world and the needs of employers. The paper will also report the challenges faced to active participation in CDIO and to communicating the value of CDIO to colleagues, decision makers, and potential collaborators. It will discuss possible steps CDIO could take to continuously develop and to be of value to both existing and potential collaborators.

## **KEYWORDS**

CDIO membership, Value, Expectations on CDIO, Standards: all

**INTRODUCTION**

The CDIO website describes well the starting point of CDIO (CDIO, 2024): *Engineering education programs throughout much of the 20th century offered students plentiful hands-on practice: Accomplished and experienced engineers taught courses that focused on solving tangible problems. But as the century progressed and scientific and technical knowledge expanded rapidly, engineering education evolved into the teaching of engineering science. Teaching engineering practice was increasingly de-emphasized. As a result, industry in recent years has found that graduating students, while technically adept, lack many abilities required in real-world engineering situations.* A development project initiated in 1997 and started as a CDIO project in 2000. In 2004 the project funding ended and CDIO initiative started with the first CDIO collaborators.

Over the years the number of CDIO collaborators has grown steadily and reached 200 members in 2023 and the CDIO initiative currently has seven regions. At the same time the initiative has developed with new versions of standards and syllabus as well as introduced new elements of optional standards. The growth has brought together members from all over the world that share a common goal of enhancing teaching and learning in higher education. As the community is still growing, we must understand the CDIO community's expectations so that the CDIO initiative, framework, community etc. can be enabled to keep itself interesting and valuable. To gain understanding of these things a series of engagements with CDIO collaborators at the CDIO International Conference, International Working Meetings and Regional meetings were organized. These workshops explored the rationale of working with CDIO, how we can improve the CDIO initiative, and how to keep it valuable for our collaborators.

When CDIO was launched in early 2000 it was a new idea for improving engineering education. The CDIO approach fulfills the definition of an innovation as it is an idea, practice, or object that is perceived as new by an individual or other unit of adoption (Rogers, 1995). The CDIO approach is actually an organizational innovation as it refers to the adoption of an idea new to the organization (Daft, 1978; Damanpour, 1996) and it is perceived new by a program, school, faculty, or university. When universities/faculties/programs/courses consider CDIO as the framework for their engineering education they go through the 'innovation-decision process'. Rogers (2003) defined this as a process (Figure 1) through which an individual or other decision-making unit passes from gaining initial knowledge of an innovation, to forming an attitude toward the innovation, to making the decision to adopt or reject, to implementing the new idea, and finally to confirming this decision. The value of CDIO can be seen differently in various phases of CDIO implementation.

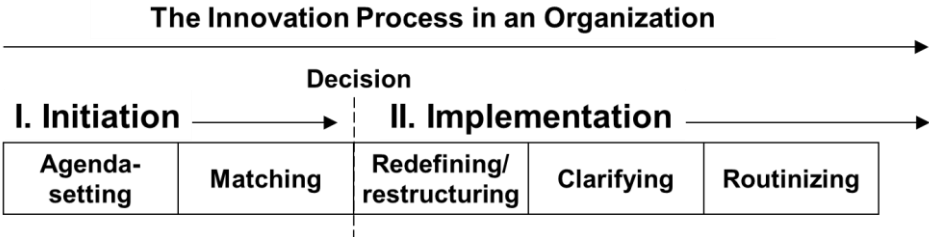


Figure 1. Innovation process in an organization.

One part influencing the adaptation CDIO approach is the characteristics of the innovation in question. The CDIO approach can offer certain value to the universities/faculties/



programs/courses going through the CDIO adaptation and implementation. Typically, an innovation can be characterized by five properties (Table 1): relative advantage, compatibility, complexity/simplicity, trialability, and observability (Rogers, 1995, 2003).

Table 1. Innovation characteristics (Rogers, 2003).

| Characteristic        | Description                                                                                                                                                                    |
|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Relative advantage    | Relative advantage is the degree to which an innovation is perceived as better than the idea it supersedes.                                                                    |
| Compatibility         | Compatibility is the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters.               |
| Complexity/Simplicity | Complexity/Simplicity is the degree to which an innovation is perceived as difficult to understand and use. Any idea may be classified on the complexity-simplicity continuum. |
| Trialability          | Trialability is the degree to which an innovation may be experimented with on a limited basis.                                                                                 |
| Observability         | Observability is the degree to which the results of an innovation are visible to others.                                                                                       |

In the next section, we go through the earlier literature regarding the value of CDIO in higher education institutions. That is followed by the research approach. The results are reflected using the innovation characteristics and innovation process definitions after the research approach. Finally, the paper discusses and concludes the key findings.

## LITERATURE REVIEW

CDIO started with 4 universities in 2001 and today the number of collaborators is over 200 higher education institutions, with new collaborators applying to join each year. The large number of universities worldwide that have adopted the CDIO approach suggests the applicability and viability of CDIO to different contexts and needs. What are the motivations of universities for joining CDIO? What are engineering educators looking for?

In an analysis of the application documents of 55 mainly European universities, Kontio (2017) found 3 main reasons:

1. **Observability:** The information about CDIO and its application in different contexts is visible and available. CDIO provides the universities with a community and network of similar minded universities that they can learn from and share their own experiences.
2. **Compatibility:** The CDIO approach and framework is compatible with their university's own vision on education development and with the development actions taking place.
3. **Relative Advantage:** CDIO features a systematic approach for designing and continuously improving education. It is a good model and standard for engineering education. It allows for fast and efficient re-design of programs and supports the development of quality engineering education.

Similarly, from a survey involving 46 universities from 22 countries, Malmqvist et al (2015) found that, in addition to the systematic approach for education reform, the main motivation to join CDIO were the methods for making engineering education authentic and the desire to include more design and innovation in curricula. The CDIO Syllabus and CDIO Standards are the

frameworks used by universities to re-design their curriculum and integrate the knowledge and skills required by working life. The outcomes of the CDIO implementation were positive. Most universities successfully achieved their goals for improved learning of CDIO, personal and interpersonal skills, for external recognition of educational quality like accreditation, government awards, and collaboration with other universities. There was also strong agreement among the respondents related to improvements to alumni and students' satisfaction ratings, better final degree reports or capstone design projects, graduate employability and recognition. However, the effects of CDIO implementation on student recruitment, retention and higher pay for graduates were less discernable. A deeper study of the evaluation of the long-term (5 years or more) implementation of CDIO in their curriculum by Pick et al (2021), Cheah et al (2013), Martins et al (2013) and Malmqvist et al (2010) found similar results. On the other hand, Edvardsson Stiwne and Jungert (2007) found that students from CDIO-based curricula found themselves more prepared for the job market than students from non-CDIO-based curricula.

In the studies above, the successes of CDIO implementation were attributed to

1. Factors relating to university and management like the alignment of CDIO with the university's vision and strategy, strong management support of the CDIO implementation, and the association of CDIO implementation with accreditation and national awards;
2. Factors relating to the CDIO framework and approach like focus on the professional role of engineers, ease of customization for the local context, structured yet flexible framework, a common language for curriculum design and development, and a strategy for the integration of learning of generic competencies in the curriculum; and
3. Factors relating to faculty and students like early adopters who are willing to experiment and fail, communication and sharing to get faculty buy-in, support from faculty developers, and management of student expectations, especially with regards to the importance of learning non-technical skills.

Meikleham et al. (2018), Malmqvist et al (2019) and O'Connor et al (2023) analysed the trends, directions and influence of CDIO via bibliometric data analysis of CDIO publications. All 3 authors noted that the growth of CDIO publication had reached a relatively steady state after 2011, likely in the absence of major changes in the approach. Their study also showed that CDIO papers focused mainly on active learning, integrated learning experiences, integrated curriculum, and design-implement experiences with fewer analysis on other CDIO features like faculty competence and learning assessment. They shared the same sentiments as Kamp (2021) that there is a risk of diluting the uniqueness of the CDIO initiative as a holistic framework for educational reform if there is an overemphasis on project-based learning.

While there was general agreement on the positive outcomes and value of implementing CDIO, Kamp (2021), raised the danger of CDIO, as a community of practice, "winding down", particularly when the "members feel the group has achieved its objectives or is no longer providing the value" and observed the first signs of winding down in some regions. He questioned the value of the existing focus on the CDIO syllabus and standards, its emphasis on student CDIO projects, and the sharing of CDIO implementation to experienced collaborators, especially in the evolving higher education landscape, driven by technology advancements and societal changes.

Given the trends in CDIO publications and the focus of the community, several recommendations have been made to the CDIO Initiative by the different authors. They include:

1. Renewal of the CDIO vision (Kamp, 2021; Malmqvist et al., 2015)

2. Adopt an open flexible and evolving CDIO framework considering the advances in technology and changing demands and needs of industry, society, and higher education. This would include the opportunities to incorporate blended and experiential learning, multi- and interdisciplinary studies, digitalization and sustainability (Kamp, 2021; Malmqvist et al., 2015; Meikleham et al., 2018)
3. Focus also on other “underserved” standards, like faculty development and learning assessments, besides design-implement and project work, to maintain the holistic nature of the CDIO framework for education reform (Kamp, 2021; Meikleham et al., 2018)
4. Evolve and increase evidence-based practices within engineering education to demonstrate the uniqueness of the CDIO curriculum and graduates. (Kamp, 2021; O'Connor et al., 2023)
5. Further the development of collaboration and engagement, particularly of CDIO researchers who are contributing outside the CDIO conferences and meetings, and communities in regions that are “winding down” (Malmqvist et al., 2019)
6. Connect with industry and accreditation agencies to promote the awareness and recognition of the “CDIO engineer” (Kamp, 2021; Malmqvist et al., 2015).

In conclusion, while the CDIO membership has continued to grow since the inception of the initiative and achieve the objectives of its members, it is necessary for the initiative to continue to take stock of its status quo and assess its value to its members, particularly in the ever changing and challenging environments that its graduates will live and work in.

## METHODOLOGY

This paper reports on a series of engagements with CDIO collaborators at the CDIO International Conference in Trondheim, International Working Meeting in Turku and Regional meeting in Batangas. The details of these international workshops are shown in the Table 2. The series of workshops initiated from the CDIO activity plan from 2022 where the focus was originally to discuss the CDIO value among senior CDIO collaborators i.e., what CDIO can offer to universities/programs that have been CDIO collaborators several years. The discussion was very quickly broadened to define the key value of CDIO altogether.

Table 2. Series of CDIO activities on CDIO value and expectations

| Location              | Event                              | Date          | Participants |
|-----------------------|------------------------------------|---------------|--------------|
| Turku, Finland        | International working meeting 2022 | 2.-3.11.2022  | 25           |
| Trondheim, Norway     | International conference 2023      | 26.-29.6.2023 | 27           |
| Bulacan, Phillippines | Asian regional meeting 2023        | 9.-11.10.2023 | 90           |

During these workshops different questions were discussed, but in general the topics explored the rationale of working with CDIO, how we can improve the CDIO initiative, and how to keep it valuable for our collaborators. The research reflects on the value of being in CDIO from the viewpoint of current and potential CDIO collaborators.

The discussions were documented with notes taken by the authors and notes made by the smaller break out discussion groups. The documented discussions have been analyzed with content analysis. Content analysis is a research technique for systematically analyzing written communication such as the results of workshops (Weber, 1990). It allows the researcher to analyze relatively unstructured data in view of the meanings, symbolic qualities, and

expressive content (Krippendorff, 2012). In content analysis, all answers are processed, and interesting and relevant information is collected.

The collected information was reflected with the five innovation characteristics and the CDIO values were placed along the innovation process continuum.

This research had some limitations. First, the participants of the workshops cover only the input of those CDIO universities and collaborators that attended the organized workshops. At the same time a large portion of the CDIO community did not attend the workshops and their voice is not heard for this study. Second, the concept of value was not explicitly defined rather every participant approached the question from their own perspective. Third, we did not collect exact information on participants regarding their experience in CDIO community and thus we cannot compare differences between the value expectations of rather new CDIO collaborators and very experienced CDIO collaborators. We do know that the participants represented both young and old CDIO collaborators.

## RESULTS

There is broad consensus amongst the members that CDIO provides a valuable framework for enhancing the quality of engineering education; opportunities to share, learn and benchmark their curriculum; and network with an international community of educators with similar challenges and goals.

The workshops' results on CDIO value focused on three main areas: CDIO as a framework, CDIO as a place to share and learn, CDIO as a community. As a framework CDIO provides an explicit syllabus and standards that give clear curriculum design guidance. The syllabus and standards are both state of the art, but at the same time living documents too. A shared view is that CDIO framework is easy to understand and adopt. The framework uses existing structures and ideas but supports enhancing the quality of engineering education. The added value of CDIO framework is keeping up to date in engineering education. The framework is seen as a tool to direct the development of engineering education and it is an institutional way to apply changes to programs. The CDIO approach promotes continuous improvement and all sides of engineering learning from theory to practice. An interesting remark was that there are already several non-engineering programs applying CDIO and that possibility of CDIO has not been communicated much.

Another value of CDIO is that it provides plenty of opportunities to share and learn from other CDIO universities/programs. Enhancing collaboration and partnerships with other institutes to learn and share best CDIO-related practices such as teaching and learning experiences are seen as major value. The annual conference and meetings provide an opportunity to learn from experienced people and gives you possibilities to guide positive change at your own university/program. There are plenty of opportunities to disseminate your own development work and receive valuable feedback and different perspectives on seemingly same challenges. The CDIO community provides you opportunities to visit top universities and explore their campuses and learning environments and take away actionable points to your own university. CDIO meetings offer possibilities to attend different introductory and advanced workshops that support your activities in implementing CDIO and developing your curriculum for example.

The third major value of the CDIO initiative is the community itself. The CDIO community consists of member universities which are represented by their CDIO contact persons and other faculty members from the faculties, schools and programs implementing CDIO. The CDIO Community is a rich arena of contacts and thus connecting people of different universities and countries. The community provides a forum for international engagement and visibility, staff development, and many potential collaboration opportunities. CDIO is described as an engaging and friendly community of practice addressing real teaching and learning issues without sugar-coating. CDIO is not a Top-Down community consisting of strategic partnerships of temporarily aligned university leaders. It has always been about the practicalities of course and program design, and the engineering competence of matriculated students. The community is an inclusive working alliance not a strategic alliance.

Although the value of CDIO seems to be clear and versatile there were several issues that the workshops raised to keep CDIO initiative interesting and valuable. One of the key things was that as the landscape of higher education continues to evolve the importance of keeping CDIO up to date with changes in the world and the needs of employers. Another topic named was to take care of continuity in universities and have several people involved in CDIO activities. Make it possible for new staff members to learn about CDIO, to join in CDIO meetings and conferences, and to have support for adopting CDIO. It was also discussed that making time for education research is essential and securing an arena to present engineering education focused research results. Furthermore, the role of management is important and therefore also the value of CDIO and the knowledge about CDIO must be confirmed and communicated to faculty deans and program leaders. Finally, issues relating to making participation possible and strengthening connections to industry and reaching our non-engineering programs were discussed too. As a global initiative, there are a lot of traveling required if you want to be active in the CDIO community. This sustainability issue together with the cost issue are challenges that need to be addressed in the CDIO community. As an engineering educator network, the relevance and connections to industry are essential, but how could CDIO initiative emphasize these in its' own activities or is it more of a questions of each university? There are already examples of CDIO value outside engineering and this could be a possibility to communicate more. Show that the value of CDIO is not only in engineering rather broader in higher education.

## **DISCUSSION**

The values of CDIO can be reflected with the innovation characteristics and innovation-process. As the CDIO network has over 200 member institutions now and new institutions are joining all the time, it is quite clear that CDIO approach is seen advantageous and thus bringing in Relative advantage. The value discussion showed that CDIO approach is seen consistent with the existing values, goals and needs in engineering education thus CDIO as an innovation is showing Compatibility. At the same time CDIO is seen as a framework which is easy to understand and there are activities supporting the understanding and utilization of the CDIO approach (Simplicity). The core tools of CDIO (Standards, Syllabus) are freely available for testing and trying although thorough implementation and development takes time. In principle, you can say that the CDIO approach is available to try for anybody considering adopting the CDIO (Triability). The CDIO community with its' opportunities to share and learn from each other's as well as visits to different universities provides a great opportunity to observe the results of the CDIO and to stimulate peer discussion on the implementation ideas and experiences (Observability). In practice, the value of CDIO seems to fulfill typical characteristics of an innovation. The literature review showed very similar results as the

workshop discussions during this study. Same elements of CDIO as emphasized in earlier studies are still seen important and major features and properties of the CDIO initiative.

From the innovation-process perspective the value of CDIO is a bit more complex. The value of CDIO is easily seen at the Initiation part of the innovation-process including Agenda-setting and Matching stages. When an organization in this case university/faculty/program sees a performance gap in their performance and start looking possible solutions several CDIO meetings and CDIO website provide basic information for setting the agenda and matching their challenges with the possibilities in CDIO approach. The CDIO meetings and CDIO knowledge library in the CDIO website are places to learn and gain understanding of the CDIO approach as well as match suitability of CDIO to your own needs and challenges. The CDIO syllabus and standards give different perspectives to your programme and clarify the possibilities of the CDIO approach. Furthermore, there are introductory and other workshops available.

Once the organization makes the decision to start applying the CDIO approach, showing the value of CDIO becomes more challenging. In the beginning of the Implementation-part of Innovation-process at Redefining/Restructuring-phase the CDIO standards and CDIO syllabus provide concrete examples and tools on how to improve and redefine your programmes and curricula. The value of CDIO is visible as you have concrete tools supporting your development activities even though you must adapt and translate everything to your own situation and context. When the organization moves to Clarifying and Routinizing phases of the Implementation-part the value of CDIO is more challenging to notice as it is typical that the innovation loose it's special identity. Of course, the CDIO tools are there, and the organization is applying them, but the organization must keep CDIO active, visible, and recognizable after the first years too. The CDIO approach has a tool for this continuous value expression in the form of CDIO self-evaluation. The CDIO self-evaluation provides six different levels in each of the standards and thus gives the opportunity to reflect the development activities and to keep CDIO recognizable for years on. The literature review raised the challenge of keeping CDIO interesting after the typical steps with standards and syllabus has been taken. Reflecting workshop discussion with the innovation process in organizations confirms this challenge of showing the CDIO value and keeping it visible. Figure 2. tries to place the main findings relating the value of CDIO and different elements of CDIO in different phases of innovation-process.

During the workshops the attendees identified recent new activities supporting the value of CDIO. The community established a concept of working-groups at the international conference in Aarhus 2019. At the beginning the working groups were formed by participants with a common interest in a topic related to the subject matter of the conference. Some working groups have continued their work outside conferences, and some are nowadays part of the CDIO activity plan. Working groups provide an additional valuable opportunity to the CDIO community by enlarging the activities past the typical syllabus and standard focused activities. Two examples of activities that started as working groups are the Curriculum Agility and Peer-to-Peer Support. As the workshops raised the working groups as a new possibility to CDIO initiative the literature review brought back several recommendations identified earlier. Some of these recommendations have already been worked on such as the updated vision of CDIO. However, many of these recommendations still need addressing and work.

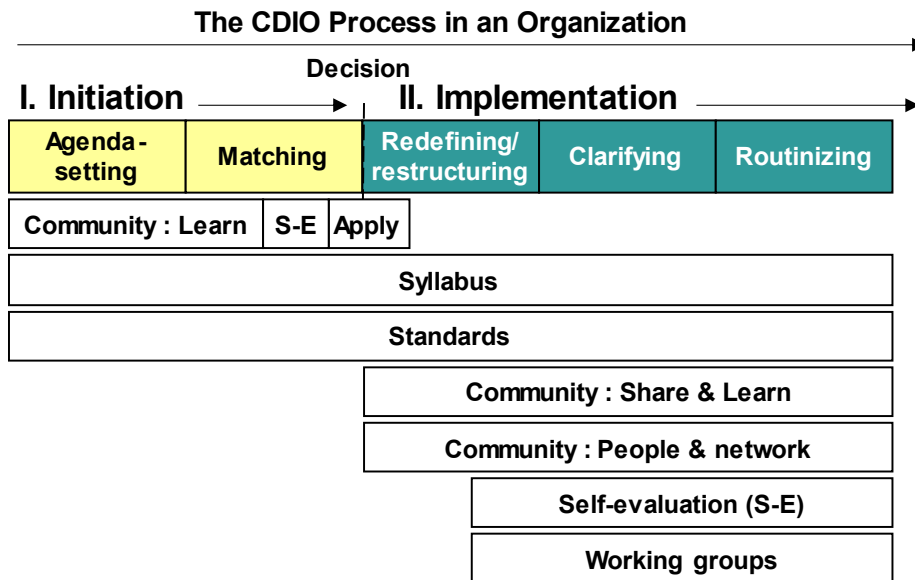


Figure 1. The value of CDIO in different innovation-process phases

## CONCLUSIONS

There is plenty of evidence that CDIO has been of value to universities and their programmes. As shown from the literature as well as from the workshops of this study, there are clearly three main values of CDIO: 1) the framework with standards and syllabus, 2) opportunity to share and learn within the network and 3) the community of people and institutions. However, we must ensure that the framework keeps on updating and developing, there are opportunities to share and learn in the future too and the community is lively and active.

At the same time the study also showed that the CDIO initiative and community is not using its full potential. The potential of this large community is vast, but it seems that most joint activities are happening in our meetings and not throughout the calendar. Therefore, we must continue to encourage more collaboration into working groups and other forms of collaboration such as peer-to-peer support activity. The CDIO initiative should also ensure that all standards are equally addressed and operated within the CDIO community. The publications focus on certain standards and less information is available on for example faculty development and learning assessment. Could we establish own working groups to these? Maybe also to some of the optional standards? Altogether, we should increase research on CDIO implications and effects. We emphasize CDIO self-evaluation when universities are joining CDIO, but nobody is asking anything after universities have joined CDIO. Should we support and build a system that helps universities to continuously utilize self-evaluation as a tool for quality enhancement? Finally, CDIO as organization has limited collaboration with other engineering bodies although collaboration/communication is happening through individual persons. Could the value of CDIO be strengthened by establishing these networks and communication channels too?

To summarize, this study basically confirmed the existing knowledge and assumptions of the value of CDIO, but at the same time it raised several possibilities to further add the value of CDIO and these topics needs to be addressed at the CDIO council meetings.

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## **II CDIO IMPLEMENTATION**

# **PEDAGOGY FOR LEARNING FROM FAILURE USING CDIO FRAMEWORK: MARINE ENGINEERING PILOT RUN**

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## **ABSTRACT**

This paper described how the pedagogy of learning from deliberate failure based on the CDIO Framework was adopted and implemented in a marine engineering course in Singapore Polytechnic. More specifically, the paper shares the results of a study whereby a set of integrated learning experiences were introduced into a 60-hour Year 2 core module entitled “Marine Engine Room Simulator Training” taken by 4 classes with a total of 59 students, over a semester. Two classes served as the experimental groups, where they received instructions from the facilitators about skills in visualization and solved additional “challenge” questions that were inserted in the learning tasks to get them to identify potential failure scenarios and consequences of selected failures. The other 2 classes function as control groups, where students learned the module in the ‘traditional’ way, i.e. without any emphasis on learning from failures. The aim is to firstly “prepare the minds”, that is to change and shape students’ attitudes toward failure in a series of learning tasks based on a marine engine simulator for the first 8 weeks before the semester break. Students learn about the engine systems of a ship, which include the generator, compressor, seawater and freshwater cooling, pump and ballast, etc. This is followed by another 7 weeks after the semester break of simulator-based training. Here the students are required to make use of the first 8 weeks’ prior learning to work through various exercises simulating shipboard operation of preparing the engines for departing port, watch keeping at sea, and arriving port. Learning experiences from the 2 groups of students are compared, firstly via a pre-test post-test survey administered at the beginning and end of the semester. 2 questionnaires are used: the School Failure Tolerance Scale and the Kirton Adaptor-Innovator Inventory. Each student is also required to submit a reflection journal, to enable comparison of attitudes toward failure between the 2 groups. Lastly, a quick comparison of the students’ assessment marks is also shared. The results showed that the failure tolerance of students from experimental group had decreased, contrary to expectations, although statistically the difference is not significant. This outcome, plus the input from reflection journals and assessment scores yield insights other factors that can affect students’ engagement in the learning tasks and suggested that more needs to be done to improve the students learning experience in learning from deliberate failure.

## **KEYWORDS**

Deliberate Failure, Marine Engineering, CDIO Core Standards 1, 2, 3, 6, 7, 11, 12

## INTRODUCTION

At the 2023 International CDIO Conference, Cheah (2023) introduced a pedagogy for learning from deliberate failure formulated using the CDIO Framework. “Deliberate Failure” in this context means that educators deliberately designed learning activities with elements/difficulties that will lead to students encountering challenges to complete the prescribed task, i.e. “failure”. It thus builds on the insights that (i) failure constitutes powerful potential learning moments; (ii) but this often happens implicitly which limits the learning potential; (iii) it can thus be introduced into the curriculum more deliberately so that students are exposed to learning from failure in a safe environment.

### ***About Learning from Failure***

Literature reviews by Cheah & Thijs (2023) showed that there are 2 major desired outcomes from engaging in tasks designed to make students learn from failure:

- (a) Promote innovation – this is by far the most common use of learning from failure, in areas of product design where one iterates from one prototype of another. This is usually associated with creativity and creative thinking in problem-solving. This type provides a context where there are no set guidelines students need to follow since the solution to specific design questions is not yet known.
- (b) Ensure safe operation – this is the main learning outcome for courses intended to prepare graduates to work in “high-risk” industries involving complex systems such as nuclear power plant, chemical processing, and aerospace. Failure in any of the processes is to be avoided at all costs so as to ensure a safe and reliable operation. This provides a context where students have to deal with standard operating procedures; and learning from failure here serves as a reminder that such failures are to be avoided at all costs.

The various reasons for failure in Case (a) may involve students missing out on key insights from a user empathy study when conceiving potential solutions; or using the wrong assumption in the design of a device, or wrong choice of materials; underestimating the resources needed for a key task; or the whole cornucopia of factors during the process of conceiving, designing, implementing, and operating a product, process, system or service. Failure can be introduced deliberately to stress-test one’s product or actively try to disconfirm existing assumptions which, in turn, may lead to a more innovative design. On the other hand, Case (b) may involve students unable to resolve a simulated operational problem in a chemical processing plant, for example, in identifying the underlying causes of the problem because the student is unable to discern the plausible cause-effect relationship among a plethora of process alarms (temperatures, pressures, flow rates, etc); and hence failed in taking the proper corrective actions to return the processing plant to its stable operating conditions. The negative consequences can deteriorate very quickly in such time-sensitive events. For training, failure can be introduced deliberately here as the classroom can provide a safe space for students to experience failures without the potentially catastrophic consequences.

### ***Learning from Failure: Improving Safety in Complex Systems***

In a nutshell, the pedagogy proposed by Cheah (2023) is aimed at addressing the challenges posed by Case (b) above. The pedagogy firstly outlines the general principles for integrated curriculum redesign using CDIO, that progressively shapes students’ attitudes toward failure, from “one of fearsome to one of welcome”: developing skills and attitudes such as critical thinking, systems thinking, resilience and perseverance. A series of integrated learning experiences can then be designed based on increasing levels of difficulty to develop these

skills and attitudes. An example of how such as the approach can be used as roadmap for curriculum redesign was illustrated using chemical engineering as an example. The aim is to better prepare students to work in industries typically classified as those made up of complex systems (Cook, 1998, 1999, 2020), of which chemical plant operation is one example. Some key characteristics of complex systems include: (i) they contain changing mixtures of failures latent within them; (ii) they always run in degraded mode; (iii) changes to the system can introduce new forms of failure; (iv) safety is a characteristics of systems and not of their components; (v) views of 'cause' limit the effectiveness of defenses against future events, and (vi) failure-free operations require experience with failure.

### ***About the Singapore Maritime Academy, Diploma in Marine Engineering and the module Marine Engine Room Simulator Training***

The Singapore Maritime Academy (SMA) is one of 10 academic schools in Singapore Polytechnic (SP). It offers specialized programs for the maritime sector, including the Diploma in Marine Engineering (DMR). This program focuses on the operation and maintenance of ship engines and machinery, aligned with the International Maritime Organization's (IMO) Standards of Training, Certification and Watchkeeping (STCW) Code Table A-III/1 (see Appendix 3), which is commonly referred to as IMO Certificate of Competency (CoC) standards. After attainment of the required competencies, DMR students at SMA will be awarded the Class 5 Certificate of Competency. Graduates often start as junior engineer officers in shipping and ship management firms, advancing their careers and competency levels over time.

The module selected for this study on impact of learning from failure is a 60-hour Year 2 core module entitled "Marine Engine Room Simulator Training" taken by a total of 59 students allocated into 4 classes. The module was delivered within 1 semester, i.e. 15 weeks of study. The semester is made up of 2 terms: 8-weeks of Term 1 and 7-weeks of Term 2; with a 3-week term break in-between.

The module learning outcomes are as follows:

1. Know the propulsion plant arrangement, instrumentation & control systems and operational procedures.
2. Apply safe operational procedures to prepare various systems (sea water and freshwater cooling, compressed air, fuel oil, lube oil)
3. Apply safe operational procedures to prepare and start auxiliary machinery.
4. Apply safe operational procedures to prepare main propulsion engine for starting.
5. Apply knowledge, understanding and proficiency to monitor the engine performance.
6. Apply knowledge, understanding and proficiency to detect the faults in the machinery system and take immediate remedial action for safe operation of the plant.
7. Apply knowledge, understanding and proficiency to maintain safe engineering watch.
8. Apply correct procedures to response promptly to various engine room emergency situations.

## **CONTEXT FOR STUDENT ENGAGEMENT**

Figure A1 in Appendix 1 shows the engineering learning workspaces for the module. The engine room simulator complex consists of the full-size engine room in which the machinery is laid out in 3 platforms, and a set of Power Plant Trainer (PPT) Workstations in a control room that simulates the operation of the engine room, which is based on the behaviour of main propulsion and the associated auxiliary machinery of a large crude oil tanker of 180,000 dwt.

The mean draft of this vessel is 18 metres, and the maximum operational speed is about 15 knots. In the physical plant, the various machinery, pipelines and fittings are not thermodynamically or mechanically loaded. Students can walk around the plant and identify the different components and learn how they are connected to one another. The plant components are fitted with sensors, switches, gauges and other instruments that allows students to interact with the engine via local panels on the platform, and workstations consoles in the control room.

Students in the DMR program are required to demonstrate evidence of competency in the following areas specified in the IMO CoC (i.e. STCW Code Table A-III/1):

1. Maintain a safe engineering watch.
2. Use the English language in written or oral form.
3. Use communication systems.
4. Operate main and auxiliary machinery and associated control systems.
5. Operate fuel, lubrication, ballast and other pumping systems and associated control systems.
6. Operate electrical, electronic and control systems.
7. Maintenance and repair of electrical and electronic equipment.
8. Appropriate use of hand tools, machine tools and measuring instruments for fabrication and repairs on board.
9. Maintenance and repair of shipboard machinery and equipment.
10. Ensure compliance with pollution-prevention requirement.
11. Maintain the seaworthiness of ship.
12. Prevent, control and fight fires on board.
13. Operate lifesaving appliances.
14. Apply medical first aid on board ship.
15. Monitor compliance with legislative requirements.
16. Application of leadership and teamworking skills.

Essentially, the learning of the above areas is conducted as follows: Term 1 was used for “*Preparing the Mind for Learning from Failure*” whereby students first familiarize themselves with the engine room and PPT operation; and able to prepare all the different components (seawater and freshwater cooling systems, compressed air system, lube oil and fuel oil systems) to prepare the ship from cold start-up all the way to main power start-up to sail out from the harbour. Term 2 is then used for “*Applying Lessons Learnt from Failure in Operation*” whereby students apply what they had learnt in Term 1 to get the generator started up and ready the ship. They will work through various exercises simulating shipboard operation of preparing the engines for departing port, watch keeping at sea, and arriving port.

### ***Application of the CDIO Framework in Brief***

This follows the ‘typical’ CDIO approach of addressing the following 3 key questions:

1. Need: What is the professional role and practical context of the profession?
2. Learning outcomes: What knowledge, skills and attitudes should students (and adult learners) possess as they graduate from our programs, and at what level of proficiency?
3. Curriculum, workspace, teaching, learning and assessment: How can we do better at ensuring that students and adult learners learn these skills?

Cheah (2023) had shared how the relevant CDIO standards can be used to guide the design of curriculum featuring Assessment learning from failure. The needs and context for learning are pretty much defined by the requirements of the Certificate of Competency standards from the International Maritime Organization (IMO). In CDIO, we are interested in learning outcomes related to skills and attitudes needed in the achievement of the desired technical outcomes. In this work, the learning outcomes are similar to that articulated by Cheah (2023) in terms of getting students to understand the relationships between process variables (flow, temperature, pressure, level) in the operation of the ship engine. Figure 1 shows a simplified relationship between selected CDIO core standards used in guiding the design of learning tasks.

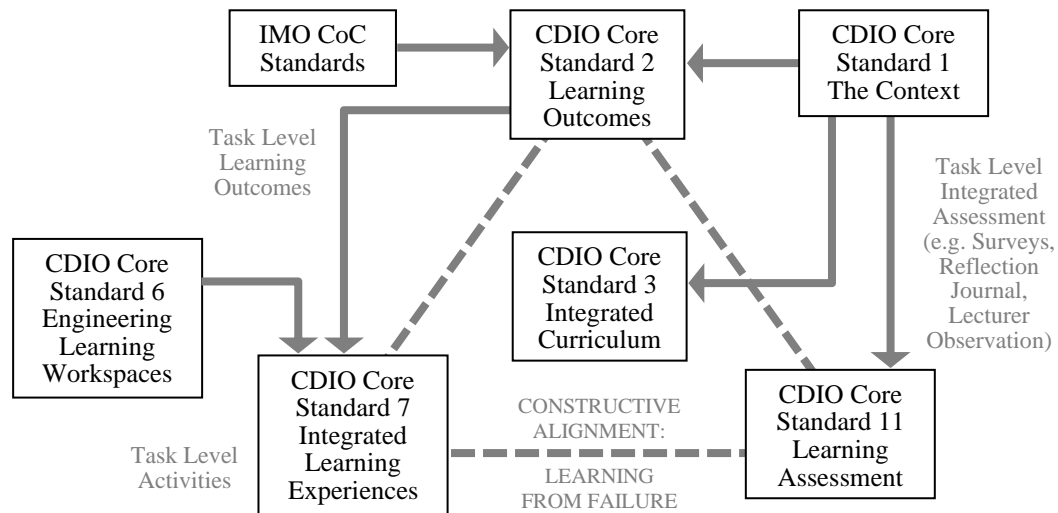


Figure 1. Application of Selected CDIO Standards in Designing Learning from Failure

## INTEGRATED LEARNING EXPERIENCES TO PROMOTE LEARNING FROM FAILURE

The learning progression for the module “Marine Engine Room Simulator Training” over the semester is shown in Appendix 2, Figure A2. A key feature of the training is that students get to repeat what they learned from the previous week’s lessons in the present week as made progress in weekly learning in gradually readying the ship to set sail. This lends itself readily for the introduction of interventions for learning from deliberate failure.

Of the 4 classes that took this module, 2 classes (2A/21 and 2A/24) served as the experimental group, where they received instructions from the Facilitators about skills in visualization and solved additional “challenge” questions that were inserted in the learning tasks to get them to identify potential failure scenarios and consequences of selected failures. The other 2 classes (2A/22 and 2A/23) function as the control group, where students learned the module in the ‘traditional’ way, i.e. without any emphasis on learning from failures. In the control group, the lecturers walk the students through the entire process, telling them what to do at each stage; and also observe students replicating the process. The whole learning is very procedural in nature, aimed at students being able to successfully complete each task as required in the manual. Even when students made mistakes and alarms sounded, they were briefed on the nature of such alarms and guided in the corrective actions to take. In contrast, for the experimental group, students were still guided but more prompting and questioning. The experimental group also has the additional challenges designed into the learning tasks that include deliberate failure in some of the tasks they had successfully completed in earlier sessions. Marks for the completion

of the tasks are not affected by the inclusion of learning from failures for the experimental group, as the challenge questions posed are formative in nature.

Since students work in groups of 4-5 members, we also took advantage of introducing peer learning in selected tasks, whereby different groups of students encountered different types of failures (see summary in Tables 1 and 2, and examples given below). Hence, they will have to teach one another in order to gain a more complete understanding of how different failures may occur. In this manner, collectively everyone will gain more from the exercises.

### ***Term 1: Preparing the Mind for Learning from Failure***

Table 1 shows the “interventions” implemented at selected learning points for Term 1. The activities were designed using the approach suggested by Cheah (2023). It is meant to address the first part of the learning from failure pedagogy: that is to prepare the students’ mind towards learning from failure namely through visualization of the processes involved, and anticipating in advance plausible failure, and potential consequences of a failure. They are reminded that such learning went forgetting certain operating procedures. The activities also attempted to develop students’ abilities to analyze relationships among key process variables for the ship engine, power and auxiliary systems as displayed in the performance dashboard. This will address the challenge of “unknown known” among students – they don’t know what they had learnt earlier, as they are not able to make connections between lessons learnt; crucial in the analysis of causes of failure (Cheah, 2023).

#### ***Example 1: Failure during Main Power Start-Up***

2 groups of students will be given Challenge Case A, while another 2 groups will be given Challenge Case B, as explained below. In both cases, students need to analyze and understand the relationship between process variables to make sense of the changes reported in the system dashboard.

- Challenge Case A: Sea chest blocked with plastic or other garbage; or strainer plugged with varying degree of dirt.
- Challenge Case B: LT Fresh Water Pump with varying degrees of low suction pressure, which could be due to pump wear.

#### ***Example 2: Failure during Auxiliary System Start-Up (1)***

This activity is again to expose students to the relationship between process variables in another important item in the ship’s engine. Facilitator will load exercise with any of the following issues causing high compressed air temperature.

- Varying degrees of low LT Fresh Water Pump pressure, where potential causes could be air leak on the suction side or pump problem.
- Varying degrees of dirty compressor intercoolers, and its impact on system performance in terms of affected process variables (namely temperature and pressure), from which students will infer the “health status of the system.

#### ***Example 3: Failure during Auxiliary System Start-Up (2)***

Facilitator loads exercise with possible conditions of dirty coolers, filters on fuel, lube oil, air and water. Students need to identify the cause and take appropriate action before "BROWN OUT" or "BLACK OUT" occurs. (The term BROWN OUT refers to a situation where some of the machinery stops functioning due to temporary loss of electrical power, while BLACK OUT



refers to total loss of electrical supply which triggers a complete shutdown of the ship's propulsion plant which can be detrimental to the ship's safety should the ship be in congested waters or arriving or leaving port). This is where students need to understand the relationship between the various process variables to ascertain the source of failure(s).

Table 1. Lesson Plan for Term 1 Activities where Interventions were introduced

| Term 1 - Familiarization |                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Week No.                 | Brief Description of Activity                                                                                                                                                                                                                                                                                                                      | Intervention to promote learning from failure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 1                        | Cold Ship Start-Up (1)<br><i>Familiarization with Engine Room and Power Plant Trainer</i>                                                                                                                                                                                                                                                          | A survey was administered to ALL students on their attitudes toward failure.<br>In the initial familiarization in Week 1, and subsequent learning in Week 2; students learnt to start the emergency generator whereby conditions for start-up (e.g. battery, fuel oil, lube oil and cooling water level) were all met. In Week 3, some of these conditions were deliberately engineered to be at failed state. Students learnt to visualize the start-up process on the sequence of tasks to be completed, and potential failures in the task that can affect successful startup of the emergency generator with a given time frame. |
| 2                        | Cold Ship Start-Up (2) <i>Seawater Cooling Systems Fresh Water Cooling Systems</i>                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 3                        | Cold Ship Start-Up (3)<br><i>Compressed Air System</i>                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 4                        | Main Power Start-Up<br><i>Diesel Generator Start-Up and Paralleling</i>                                                                                                                                                                                                                                                                            | In performing this task, students will encounter challenges in prior tasks such as seeing an alarm in the seawater or freshwater system (week 2); and failure to undertake the proper corrective action can result in a shutdown of the system.                                                                                                                                                                                                                                                                                                                                                                                      |
| 5                        | Auxiliary System Start-Up<br><i>Fuel Oil System Lube Oil System</i>                                                                                                                                                                                                                                                                                | In performing this task, students will encounter challenges in prior tasks such as seeing an alarm in the compressed air system (week 3); and failure to undertake the proper corrective action can result in a shutdown of the system.                                                                                                                                                                                                                                                                                                                                                                                              |
| 6                        | Auxiliary Boiler Start-Up<br><i>Steam Generation</i>                                                                                                                                                                                                                                                                                               | In performing this task, students will again make use of prior learning to identify from the information shown in the dashboard, the plausible cause of failure from a range of possibilities.                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 7                        | Continual Assessment 1 (INDIVIDUAL, 1-hr, 40%): Learning Journal<br>All students (control and experimental groups) submit a report comprising answers to questions posed in each activity for the past 6 weeks. The experimental group is not required to include the answers to the challenge questions.<br>Reflection by Experimental Group only |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 8                        | Mid-semester Test Week – No lesson for this module                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 9-11                     | Term Break (3 weeks)                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

### *Reflection: Learning Experience*

Students from the experimental group are required to submit an individual reflection journal on their learning experience, and answer the following questions based on Gibbs' Reflective Cycle:

- Description of the Experience: What happened?
- Feelings and Thoughts about the Experience: What were you thinking and feeling?
- Evaluation of the Experience: What was good or bad about it?
- Analysis to Make Sense of the Situation: Why was it good or bad?
- Conclusion about the Situation: What you learnt and what you could have done differently?
- Action Plan: What will you do differently?

### **Term 2: Applying Lessons Learnt (in Term 1) from Failure in Operation**

Table 2 shows the activities students will undertake in Term 2, continuing to build on the learning gained in Term 1. For this paper, we are interested in students learning from failures up to the point when they ready the ship to depart from port and set sail. Their learning will be put to test in Continual Assessments 2 and 3, which are further elaborated below.

For Term 2 activities, similar failures as introduced in Example 1 in Term 1 can again be introduced, but with more variation to see if students are able to identify other causes in addition to what they had learnt earlier. For instance, in a variation of Case A, the sea chest is now blocked with ice; which necessitates different corrective action: instead of using compressed air to flush the section, steam should be used to melt the ice! For Case B, the deterioration of LT Fresh Water Pump performance could be due to reduction in pump speed.

Table 2. Lesson Plan for Term 2 Activities where Interventions were introduced

| Term 2 - Operation |                                                                                                                                                                                                              |                                                                                                                                                                                                    |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Week No.           | Brief Description of Activity                                                                                                                                                                                | Intervention to promote learning from failure                                                                                                                                                      |
| 12                 | <i>Revision of Term 1</i><br>Start of Parallel Generator – <i>after going through the steps in Term 1</i>                                                                                                    | Facilitator gave a quick recap of lessons learnt from challenge questions in Term 1. Students are asked to reflect on the failure(s) encountered during the start-up process.                      |
| 13                 | Continual Assessment 2 (INDIVIDUAL, 1-hr, 30%): “Cold Ship Start Up to Own Power”<br>Each student is to demonstrate his/her understanding from all earlier lessons.<br>Reflection by Experimental Group only |                                                                                                                                                                                                    |
| 14                 | “One Hour Notice” Preparation to leave port and set sail<br><i>Lube Oil Purifier Start up</i>                                                                                                                | In performing this task, students will encounter challenges in starting up the Lube Oil Purifier and failure to undertake the proper corrective action can result in loss of main engine lube oil. |
| 15                 | Repeat of “One Hour Notice”<br>Leaves port and set sail                                                                                                                                                      | “Full away procedures”, No intervention planned                                                                                                                                                    |
| 16                 | Out at Sea: Keeping watch duties and responding to alarms                                                                                                                                                    | Facilitator simulates various alarm conditions for practice                                                                                                                                        |
| 17                 | Continual Assessment 3 (INDIVIDUAL, 1-hr, 30%): “One Hour Notice to Departure” and set sail. Each student is to demonstrate his/her understanding from all earlier lessons.                                  |                                                                                                                                                                                                    |
| 18                 | Set Aside for Make-Up Lessons, if needed                                                                                                                                                                     |                                                                                                                                                                                                    |
| 19-20              | Semestral Examination (2 weeks) – Not Applicable for this Module                                                                                                                                             |                                                                                                                                                                                                    |

#### *Example 4: Failure to bring up Parallel Generator*

For the first activity in Term 2, failure to start the parallel generator mostly stemmed from failure to carry the process in the prescribed manner. What was done differently between the experimental and control groups was that students from the experimental group were asked to reflect on what they did wrong, and why the following the steps mattered. On the other hand, students from the control group were told what went wrong and had the steps explained to them by the Facilitator.

#### *Continual Assessment 2 (30%): Cold ship Start up to Own Power*

This is a summative assessment, administered individually. Students essentially has to demonstrate competency in getting the ship to operate on Main Power by going through all the steps from cold start (Week 1, Term 1 in Table 1) to starting the first main Generator (Week 4, Term 1 in Table 1). The experimental group was required to submit a reflection journal using the same Gibb's Reflection Cycle form used in Term 1.

#### *Example 5: Failure to successfully operate the Lube Oil Purifier*

In the next activity, after successfully started the parallel generator, students will also need to bring into operation the lube oil purifier. Facilitator will take note of how many students still made mistakes in this key step. Facilitator will also demonstrate an example of failure to emphasize that even when all start-up procedures were adhered to correctly. Facilitator will explain the cause and effect to students from the control group, For the experiment group, the cause of the introduced failure will not be made known to students. Students will be asked to provide plausible reasons that can lead to a failure, and potential consequences of each failure. Facilitator can also different failure scenarios for different experimental groups, again to promote peer learning). This will set the context for Continual Assessment 3.

#### *Continual Assessment 3 (30%): Preparing to Sail out of Port*

This is a summative assessment, administered individually. Students essentially have to demonstrate competency in getting the ship ready to leave port, by going through all the steps from cold start (Week 5, Term 1 in Table 1) to starting the parallel generator (Week 15, Term 2 in Table 2) as well as the various systems required to operate the main propulsion plant. Although both groups (experimental and control) will go through the same assessments, Part 1 of the assessment (out of a total of 4 parts) is of interest for this work as the question here pertains to how they problem-solve the challenges posed, and we wished to see if there are differences in answers from students from the 2 groups.

## **FINDINGS FROM STUDENTS ON THEIR LEARNING EXPERIENCES**

2 surveys were carried out for all students (both experimental and control groups) in order to find out their learning experience: a pre-test survey at the beginning of Term 1 (i.e. start of semester) and a post-test survey in Term 2 (i.e. end-of-semester). For each survey, 2 sets of questionnaires are used – the School Failure Tolerance Scale (SFTS) (Clifford, 1988) and the Kirton Adaptor- Innovator (KAI) Inventory (Kirton, 1976). We also compared both groups of students' assessed work, namely the continual assessments as noted in Table 1 and Table 2. In addition, the experimental group is also required to submit a reflection journal for their learning.

Due to time constraint, we did not manage to conduct focus group discussions with the students.

### **Results from Students Surveys: Pre-Test and Post-Test**

First, we share the survey findings from the 2 groups of students. A total of 44 students responded, comprising 26 students from the experimental group (100% responses) and 18 from the control group (where 18 out of 33 responded, a rate of 54.5%). The average SFTS score, and KAI score are shown in Table 3.

Table 3. Failure Tolerance and KAI scores of Students: Pre-Test vs Post-test

| Group        | Average SFTS Score                 |                                   |         | Average KAI Inventory Score        |                                   |         |
|--------------|------------------------------------|-----------------------------------|---------|------------------------------------|-----------------------------------|---------|
|              | Pre-Test<br>(Start of<br>Semester) | Post-Test<br>(End of<br>Semester) | p-value | Pre-Test<br>(Start of<br>Semester) | Post-Test<br>(End of<br>Semester) | p-value |
| Total        | 2.961                              | 3.039                             | 0.1610  | 2.900                              | 2.870                             | 0.4896  |
| Experimental | 3.020                              | 3.000                             | 0.7950  | 2.865                              | 2.910                             | 0.2959  |
| Control      | 2.875                              | 3.095                             | 0.0051  | 2.952                              | 2.812                             | 0.1112  |

Focusing on the average SFTS Scores in Table 3, we can see that the results were the exact opposite of what we expected, i.e. there is an increase in failure tolerance for the control group instead of the experimental group, even though they are not statistically significant. This is partly due to the small sample sizes for both groups. We can say that the two groups of students have similar failure tolerance levels. The counter-intuitive results would appear to suggest that students from the experimental group had become less “failure-tolerant” as a result of the various interventions introduced. One way to interpret this is that students from the experimental group, having been exposed to a different way of carrying out the simulated tasks – one with more probing from lecturers and a good dose of additional challenges questions – felt more intimidated or less confident when they realized that some scenarios are more complicated than they anticipated, beyond just follow the operating procedures. On the other hand, the students from the control group may have grown accustomed to the procedures as they were guided every step of the way by the lecturers, and they their confidence grew, resulting in higher “failure-tolerance”.

Turning to the KAI Inventory Score, likewise statistically the difference between the experimental group and the control group score for KAI inventory is also not big enough to be significant. Curiously, the results for the KAI Inventory Score were reversed for the experimental vs control groups. This seemed to suggest that students from the experimental group developed more propensity to think differently as a result of being exposed to more challenging questions.

Besides that, we can also speculate that all students had not been exposed to any prior briefings on learning from failure; especially for the experimental group. They were not explicitly informed of any possible encounter beyond what they read in the laboratory manual. It can be hypothesized that they carried the same mindset as that from Year 1 – that is, “learning” means the lecturers will show them what needs to be done and. Therefore, the additional challenge may come as an unpleasant surprise to them. This can be seen in the reflection questions from the students from the experimental groups, which we elaborated more in later section.

The results suggested to us that we need to beyond average values, and to look at findings of

student scores for their assessments at the class-level as well. This is discussed in the next section. Due to time constraint, we did not manage to reanalyze the SFTS and KAI Inventory Scores any deeper into the class or student levels.

### **Analysis of Students Assessment Results**

Table 4 shows the comparison of results for both the experimental group and control group for their graded assessments, all administered individually. The acronyms used are shown in the bottom of the table.

Table 4. Comparison of Results from Graded Assessment

| Group                    | Students Background | LAS score | CA1 Mean | CA1 Std Dev | CA2 Mean | CA2 Std Dev | CA3 Part 1 Mean | CA3 Part 1 Std Dev |
|--------------------------|---------------------|-----------|----------|-------------|----------|-------------|-----------------|--------------------|
| Experimental Group 2A/21 | N- & O-levels       | 7-25      | 69       | 14.59       | 73       | 15.89       | 51              | 11.73              |
| Experimental Group 2A/24 | ITE & some O-levels | 17-20     | 71       | 12.16       | 79       | 14.42       | 52              | 3.75               |
| Control Group 2A/22      | O-levels & some ITE | 9-25      | 74       | 8.11        | 80       | 11.58       | 53              | 9.19               |
| Control Group 2A/23      | ITE & some O-levels | 19        | 76       | 4.68        | 71       | 22.76       | 52              | 15.87              |

CA: Continuous Assessment, LAS: Last Aggregate Score – a figure derived from a student’s polytechnic entry requirements based on his/her secondary school results (O- or N-levels) and serve as indicator of students’ academic ability (the lower the score, the better), ITE: Institute of Technical Education – vocational training for students who were not initially eligible for polytechnic admission after their secondary school education. They subsequently apply to polytechnics using their vocational results.

It can be challenging to look at the average results, given that students DMR came from a wide range of academic abilities (LAS scores). There were a handful of ‘better’ students (i.e. low LAS of 7-9) compared to those near the cut-off LAS for DMR intake (i.e. maximum LAS of 25). The mixing of students was based on other admissions criteria beyond the scope of this discussion. Suffice to say that the team had no control over this matter.

An interesting result comes from comparison the marks for class 2A/24 (experimental group) and 2A/23 (control group) whereby the 2 classes of students have similar academic abilities. Here class 2A/24 clearly improved from CA1 to CA2 while class 2A/23 moved in the opposite direction. It can be interpreted that 2A/24 had learnt better from the interventions despite the lack of statistical significance. However, this cannot be substantiated by the results for CA3 Part 1. All 4 classes in fact had similar mean scores but it is notable that the standard deviation for 2A/23 is much larger than 2A/24.

Also, the results also showed that broadly, despite the outcomes indicated on the SFTS scores (Table 3) students from the experimental groups still made good progress in moving from CA1 to CA2, although one needs to be mindful that the standard deviations for both classes 2A/21 and 2A/24 are still fairly large. Students from control group 2A/22 also performed well from CA1 to CA2 and this can be attributed to the stronger academic ability of these students. Performance for class 2A/23 remained anomaly especially all have the same academic ability at LAS 19. We did not manage to delve deeper into individual student scores, again due to time constraint. What we did next was to look at the reflection journals submitted by students from the

experimental groups, which is presented next.

### ***Students' Reflection Journal Entries***

Lastly, we studied entries in the Term 1 reflection journals from students from the experimental groups. A total of 23 students (out of 26) submitted. The entries were analyzed for key themes, of which 3 were identified as follows:

- a. Following procedures blindly with little real understanding of the systems and process hence feeling stressed and panicked as the mind went blank and unable to effectively think of the next course of action.
- b. Not leveraging on teamwork by seeking team members' assistance to analyze the situation and acquire the essential information for critical evaluation to achieve a solution.
- c. Not paying attention to the system's parameters that provide essential information on the operational state of the system or machinery, to critically evaluate and deduce the cause of potential failure warning via sounding of alarms.

Interestingly, a study of the entries in the Term 2 reflection journals from the same students revealed themes similar to the above: feeling stressed from having too many sequences and procedures to recall for execution. However, students in general do demonstrate greater composure when visual and audible alarms go off; and they reported that they were better able to acknowledge the alarms and carry out the proper diagnostics of the scenarios:

- a. review appropriate parameters
- b. think through possible causes and
- c. seek inputs from teammates.
- d. based on the 3 points above apply rectification steps to resolve the issues.

An insight that we obtained from the reflection journals is the influence of teamwork. It is worth noting that all exercises in Terms 1 and 2 were conducted in groups, but the assessments are based on individual efforts. It can be speculated that some students in the experimental group experienced challenging team dynamics that affected their perceived failure tolerance – positive or otherwise. We did not require students from the control group to submit reflection journals, we do not know if this group's experience with teamwork in carrying out the tasks.

Besides teamwork, another insight we obtained from the reflection journals that we did not get from looking at average scores of SFTS and KAI Inventory scales; and the average marks for the assessment components is the disposition of *each individual student* towards failure. Table 5 showed the reflection journal entries from 2 students "Ethan" and "Ryan" from the experimental group, selected on basis of demonstrating evidence of learning from the interventions administered.

It is worth noting that the 2 students are also academically stronger, a finding which we validated by going back to check on their profile and academic scores for the graded assessments. Due to time constraint, we did not manage to extract the individual students' SFTS Score and KAI Inventory Score.

Table 5. Comparison of reflection journals from 2 students in Term 1 and Term 2

| Student                                                      | Term 1 Reflection Journal                                                                                                                                                                                                                                                                                                                                                                                                        | Term 2 Reflection Journal                                                                                                                                                                                                                                                                                                                                    |
|--------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>“Ethan”<br/>(real name withheld at student’s request)</p> | <p>“Stay calm and composed, ensure correct procedures were made and also regularly check on the operational readings like temperature, pressure, level, flow rate, voltage, frequency, etc. In real life, check if equipment has been properly checked and maintained in the past few days/weeks. If equipment had been sufficiently checked and maintained, equipment breakdown/malfunctions should occur less frequently.”</p> | <p>“There are some factors outside of our control that we cannot possibly predict, even though we did everything correctly. However, we can learn from this and find better ways to improve on how fast we can identify the problems as well as maybe think of ways to find a pattern so that we can predict such problems if they arise in the future.”</p> |
| <p>“Ryan”<br/>(real name withheld at student’s request)</p>  | <p>“Before I encountered the situation, I was feeling proud because I managed to do it well during practice. But during the process, many alarms started to ring and I found it stressful because I didn’t know what is the main problem. After understanding the situation with the help of teammates I managed to overcome the stress and worked on solving the problem.”</p>                                                  | <p>“When audible and visual alarms go off during synchronization of generators, do not panic or be shocked, stay calm to check carefully and ensure proper transfer of power before proceeding to disconnect and shut down outgoing generator.”</p>                                                                                                          |

## DISCUSSIONS AND MOVING FORWARD

The entire endeavor had been a great learning experience for all 3 authors. We started off with very ambitious plans for this pilot run, while acknowledging the challenges that underpin what we can achieve within a semester, namely in terms of the time constraint, which readers will have noticed this being mentioned multiple times in the earlier section. We meant this work to be a “proof-of-concept” initiative, adopting the approach of “fail fast, fail early” to learn from the pilot run as much as possible; as we are all new to training students to learn from deliberate failure when operating complex systems.

Overall, based on the performance, results, and feedback of students in the experimental group, it can be said that the pilot run of using deliberate failure interventions shows promise of improving students’ learning using deliberate failure, but much remained to be improved. The challenges are multi-faceted, and some key areas are discussed below.

### ***Revamp of the Diploma in Marine Engineering Program***

At the time of this writing, the entire DMR curriculum is under review to better streamline the delivery of the program to meet stakeholder and institutional requirements. There are excellent opportunities to also revamp some modules *especially those is the first year to include foundational work to shape students’ view towards failure* (Cheah, 2023). Some of the key objectives of the redesign of the DMR program towards an integrated curriculum are:

- Identify gaps in students’ outcomes required by the IMO CoC and hence rectify the shortfall in coverage and achieve better alignment
- Identify coverage of existing fundamental skills and attitudes in current program structure, such as teamwork and communication to be leveraged on in supporting learning from failure

- Identify opportunities in other modules to better prepare for the learning tasks in the module “Marine Engine Room Simulator Training” to “offload” the “preparing the mind” stage coverage in this module (as described in Table 1 for Term 1). This will free up time in the module to engage students deeper in learning from failure (Table 2 for Term 2). These other modules can, for example: (a) tap on growth mindset to build up students self-efficacy and modify their perception of failure as a negative outcomes; and (b) reinforce students’ understanding of the various relationships between process variables in the operation of a s ship’s engine.

### ***Redesign of Module “Marine Engine Room Simulator Training”***

Moving ahead, more specifically on the module “Marine Engine Room Simulator Training” itself, the DMR team plans to carry out the following improvements to the module:

- Focus module delivery on the 4 major scenarios
  - (1) Cold ship to ship on own power (i.e. 1 main generator running)
  - (2) Own power to harbor condition
  - (3) One Hour Notice to Departure for Preparing propulsion plant from Harbor condition to Ready for Departure
  - (4) Watch Keeping Practice when the ship is sailing at full away sea state
- For each of the scenarios, facilitator will select and load suitable intervention(s) with deliberate failures. A facilitation guide will be prepared to help lecturers manage the learning process in a consistent manner
- Update module syllabus to capture learning outcomes for skills and attitudes

### ***Developing Lecturer Competency in using CDIO and Facilitating Learning from Failure***

It is worth pointing out that most SMA staff in general, and those directly in the experimental group in particular, are not familiar with CDIO. A series of professional development workshops had been planned for staff from SMA, to firstly acquaint them with them with the fundamentals of CDIO. Subsequent training will focus the concepts of learning from failure, the CDIO Approach towards designing an integrated curriculum, designing intervention using CDIO integrated learning experiences and learning assessment, among others. The goal is supporting the revamp of the DMR Program mentioned above.

SMA staff will also need to be trained to facilitate students learning in a different manner, moving away from the current practice. The importance of having students think differently, and to embrace learning from failure will be emphasized.

### ***Conduct Another Round of (Better planned) Intervention***

it is important to bear in mind the need for careful use of failure interventions to avoid “failure” fatigue, discouragement, and eventually de-motivation. The module will be run again for another 4 classes of students in coming semester. If necessary., we could continue to revisit the results obtained from this work, to drill down into details at the level of each student to gain better insights from each one of their learning experience that can shed more lights to improve for the next run.

With changes made to the module as mentioned earlier, we can plan for better interventions that will include a short briefings to all students, on the importance of critical thinking, and the “new” way of learning that comes with the module, which include the following:



- Challenge questions can be built into the learning tasks, requiring all students – regardless of if they are in experimental or control group – to answer them.
- Existing assessment rubrics will be improved upon to enhance consistency in grading by different lecturers taking the different classes.
- A focus group discussion will be planned into the intervention at the end of the semester.
- The questions used in the reflection journal can be crafted in more specific manner, by pointing to learning from failure; based on the generic format suggested by Gibbs.

Last, we also need to be mindful of the multitude of surveys students are already asked to complete on top of the usual student feedback surveys and teamwork surveys. This is especially true in SP, where there are additional institutional-level longitudinal surveys on self-directed learning, with a pilot run already in progress, that will eventually be extended to all students. To allow us to effectively investigate influence of teamwork in learning from failure in a group setting, we can leverage of the existing teamwork surveys to include additional (and specific) questions pertaining to learning in this module.

## **CONCLUSIONS**

This paper shared how the pedagogy for learning from failure is being implemented in a Marine Engineering program. The results are, however, inconclusive. Our students from the experimental group with additional activities on tackling failure issues showed a decrease in failure tolerance. Cross-checking evidence from other sources namely reflection journal, and assessment marks

Our study did show that when it comes to matters related to learning from failure, at least for the case of dealing with complex systems, there is a need to address each student's disposition towards failure as a mechanism for improving learning, especially when we are dealing with students of wide demographic make-up and learning abilities. This work and yield a lot of insights into ways to engage students to learning from deliberate failure. Refinements to the interventions introduced in this pilot run had been identified, as more research into this way of student engagement is implemented in this program will continue to be explored.

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## Appendix 1: SMA Marine Engine and Simulator

*Proceedings of the 20<sup>th</sup> International CDIO Conference, hosted by Ecole Supérieure Privée d'Ingénierie et de Technologies (ESPRIT) Tunis, Tunisia, June 10 – June 13, 2024*

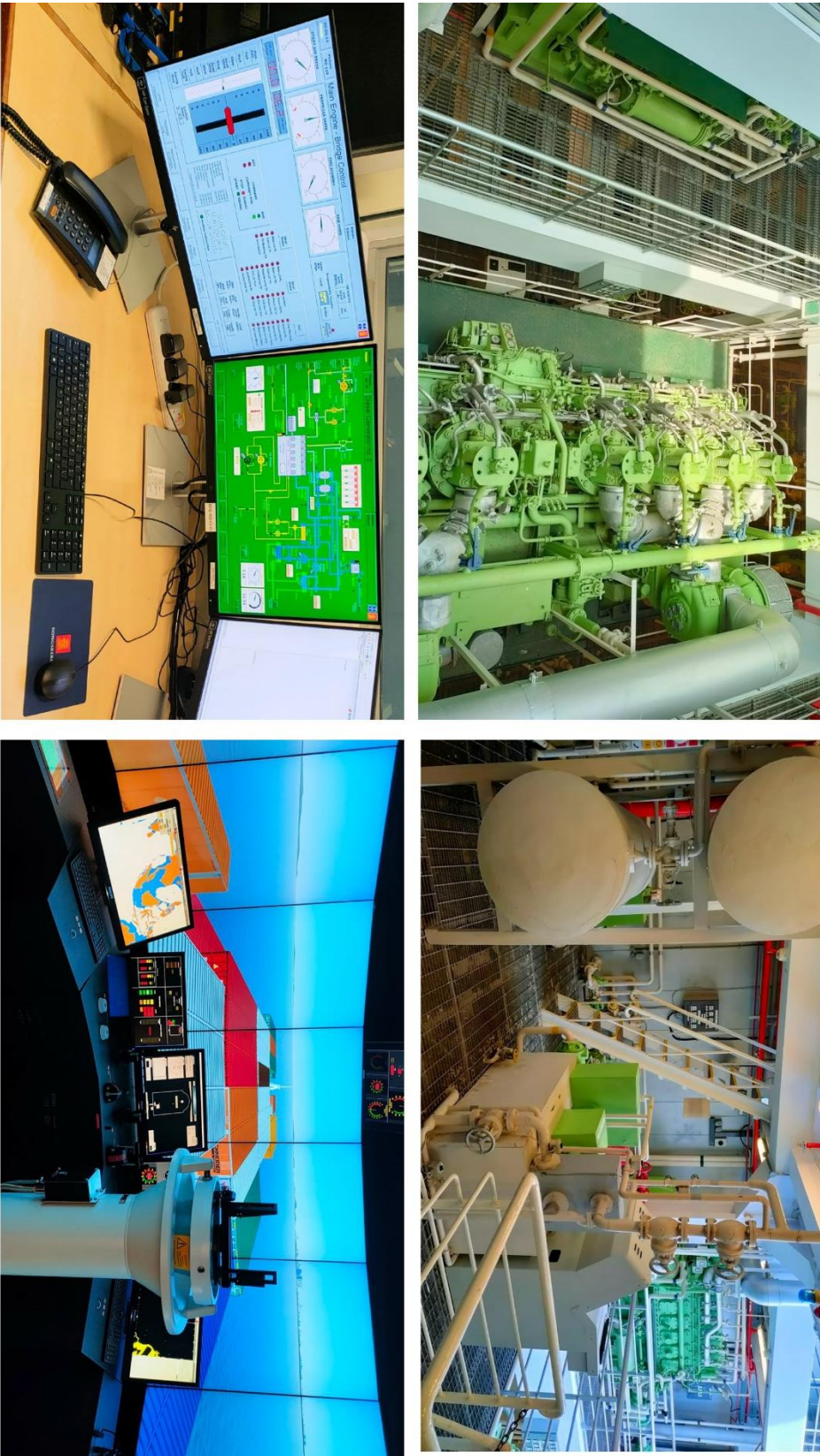
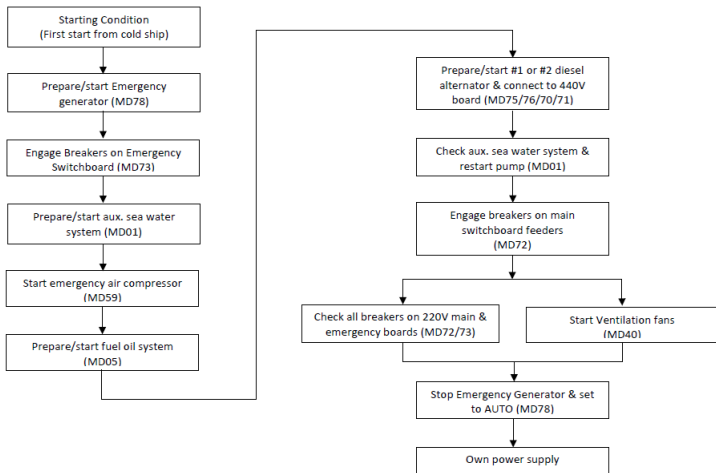


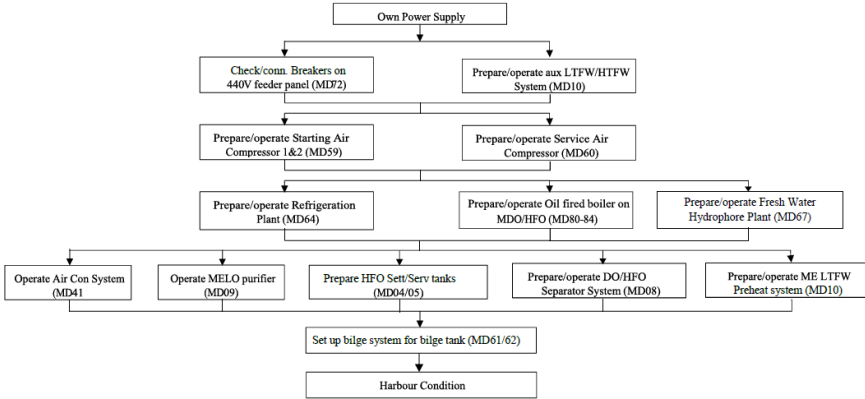
Figure A1. Physical mock-up of Engine (above) and Simulator Console with Immersive Environment (below)

# Appendix 2: Learning progression for Marine Engine Room Simulator Training

## 1.1 First Start to Own Supply



## 1.2 Own Supply to Harbour Condition



## 1.3 Harbour condition to ready for departure

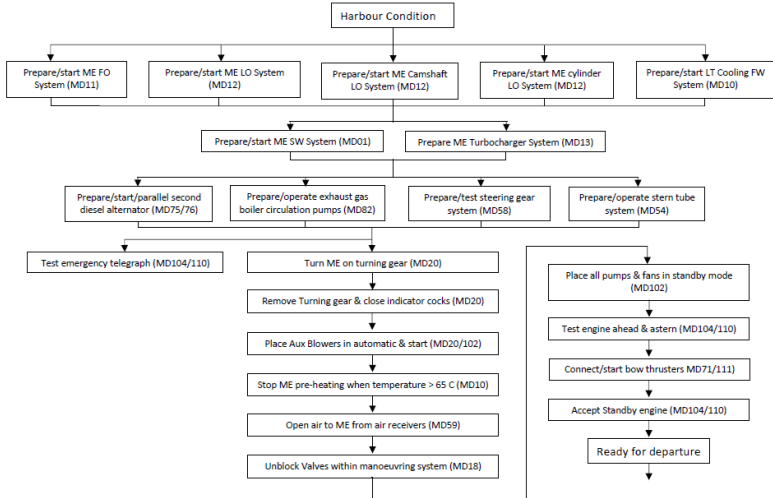


Figure A2. Learning progression over a semester of study

## **Appendix 3: IMO STCW Code Section A-111/1 Chapter III (STCW 2010 Res 2)**

### *Mandatory Minimum Requirements for Certification of Officers in Charge of an Engineering Watch in a Manned Engine-Room or Designated Duty Engineers in a Periodically Unmanned Engine-Room*

#### **Training**

1. The education and training required by paragraph 2.4 of regulation III/1 shall include training in mechanical and electrical workshop skills relevant to the duties of an engineer officer.

#### **Onboard Training**

2. Every candidate for certification as officer in charge of an engineering watch in a manned engine-room or as designated duty engineer in a periodically unmanned engine-room of ships powered by main propulsion machinery of 750 kW or more whose seagoing service, in accordance with paragraph 2.2 of regulation III/1, forms part of a training programme approved as meeting the requirements of this section shall follow an approved programme of onboard training which:
  1. ensures that, during the required period of seagoing service, the candidate receives systematic practical training and experience in the tasks, duties and responsibilities of an officer in charge of an engine-room watch, taking into account the guidance given in section B-III/1 of this Code;
  2. is closely supervised and monitored by a qualified and certificated engineer officer aboard the ships in which the approved seagoing service is performed; and
  3. is adequately documented in a training record book.

#### **Standard of Competence**

3. Every candidate for certification as officer in charge of an engineering watch in a manned engine-room or as designated duty engineer in a periodically unmanned engine-room on a seagoing ship powered by main propulsion machinery of 750 kW propulsion power or more shall be required to demonstrate ability to undertake, at the operational level, the tasks, duties and responsibilities listed in column 1 of table A-III/1.
4. The minimum knowledge, understanding and proficiency required for certification is listed in column 2 of table A-III/1.
5. The level of knowledge of the material listed in column 2 of table A-III/1 shall be sufficient for engineer officers to carry out their watchkeeping duties. \*
6. Training and experience to achieve the necessary theoretical knowledge, understanding and proficiency shall be based on section A-VIII/2, part 4-2 Principles to be observed in keeping an engineering watch, and shall take into account the relevant requirements of this part and the guidance given in part B of this Code.
7. Candidates for certification for service in ships in which steam boilers do not form part of their machinery may omit the relevant requirements of table A-III/1. A certificate awarded on such a basis shall not be valid for service on ships in which steam boilers form part of a ship's machinery until the engineer officer meets the standard of competence in the items omitted from table A-III/1. Any such limitation shall be stated on the certificate and in the endorsement.
8. The Administration may omit knowledge requirements for types of propulsion machinery other than those machinery installations for which the certificate to be awarded shall be valid. A certificate awarded on such a basis shall not be valid for any category of machinery installation which has been omitted until the engineer officer proves to be competent in these knowledge requirements. Any such limitation shall be stated on the certificate and in the endorsement.
9. Every candidate for certification shall be required to provide evidence of having achieved the required standard of competence in accordance with the methods for demonstrating competence and the criteria for evaluating competence tabulated in columns 3 and 4 of table A-III/1.

#### **Near-Coastal Voyages**

10. The requirements of paragraphs 2.2 to 2.5 of regulation III/1 relating to level of knowledge, understanding and proficiency required under the different sections listed in column 2 of table A-III/1 may be varied for engineer officers of ships powered by main propulsion machinery of less than 3,000 kW propulsion power engaged on near-coastal voyages, as considered necessary, bearing in mind the effect on the safety of all ships which may be operating in the same waters. Any such limitation shall be stated on the certificate and in the endorsement.

\* The relevant IMO Model Course(s) may be of assistance in the preparation of courses

# DYNAMIC INTEGRATION OF SUSTAINABILITY AND CLIMATE CHANGE IN ENGINEERING CURRICULA VIA CDIO

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## ABSTRACT

This paper explores the transformative potential of the CDIO (Conceiving, Designing, Implementing, and Operating) approach in adapting traditional engineering programs to accommodate the needs for sustainability and climate change perspectives. Integrating those aspects is imperative today since engineers play a pivotal role in addressing the industry's environmental impacts and meeting the demands of a changing energy landscape. Equipping students with these skills is essential to ensure graduates are well-prepared to balance industry needs with environmental responsibility. The CDIO approach, rooted in global collaboration and practical problem-solving, offers a flexible framework that aligns with the growing needs of the industry since it allows educators to seamlessly incorporate new concepts into the curricula while connecting the vertical and horizontal educational approaches. One innovative idea is to leverage the CDIO or Project-Based Learning (PBL) concept to create dynamic engineering curricula. Our experience from the Australian University in Kuwait includes case studies of PBL courses from the Petroleum Engineering Program that incorporate various sustainability aspects. In these case studies, students ventured beyond their usual curriculum, acquiring knowledge that extended to novel and essential elements. Empirical evidence from pre- and post-surveys showcases PBL's significant impact on enhancing students' understanding of sustainability concepts within engineering curricula. The study underscores the value of hands-on, project-driven learning in fostering a holistic and environmentally conscious approach among engineering students. In conclusion, this paper discusses how CDIO, emphasizing real-world application and open-architecture design, can dynamically reshape engineering education. The case studies demonstrate a successful and applicable approach, offering students a promising opportunity for skill development and acquiring new learning outcomes beyond the traditional curriculum. This dynamic adaptation promises to produce a new generation of engineers better prepared to navigate the ever-growing industry while practicing environmental stewardship and sustainability.

## KEYWORDS

Sustainability, Climate Change, Engineering Education, Dynamic Curricula, Project-Based Learning, Standards: 1, 2, 3, 8, 11.

## INTRODUCTION

Engineering education is at a crossroads that necessitates a significant shift. Traditional programs emphasize technical competence and lack critical viewpoints on sustainability and climate change, leaving young engineers unprepared for the ever-growing world. This mistake not only jeopardizes their holistic training but also risks their capacity to navigate a world increasingly affected by environmental issues. **Figure 1** depicts the present gaps in standard engineering courses regarding sustainability and climate change views.

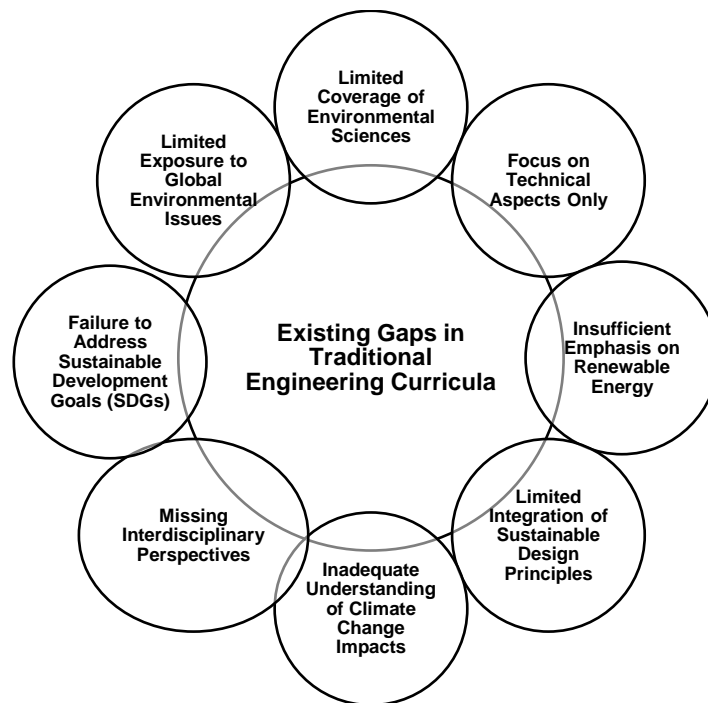


Figure 2. Deficiencies in Traditional Engineering Curricula: Gaps in Sustainability and Climate Change Perspectives

These curriculum gaps exclude critical disciplines such as climate science and renewable energy, leaving a deficit in addressing critical global environmental challenges. Engineers, however, have a crucial role in addressing these issues, which impact energy consumption, resource usage, and sustainable infrastructure.

Sustainability integration in engineering education fits with ethical duties and the Sustainable Development Goals (SDGs), addressing industrial demands for sustainable solutions. It's more than just a matter of curriculum; it's an ethical and cultural imperative enabling engineers to design a more sustainable future for the industry and the global community.

There is a distinct lack of emphasis on sustainability and environmental consciousness in mechanical and software engineering schools. While mechanical engineering avoids environmental issues in favor of specific green technology electives, software engineering lacks standardized instruction in Requirements Engineering. These difficulties highlight the need for more comprehensive techniques for integrating sustainability into engineering education (Daun et al., 2023; Sprouse III et al., 2021).

Simultaneously, initiatives to include sustainable development into curricula are emerging,

utilizing frameworks such as CDIO and the UN Sustainable Development Goals (SDGs). Despite efforts to connect digital and human skills to the SDGs, obstacles remain, necessitating a more comprehensive strategy to integrate sustainability deeply within engineering education (Cheah et al., 2022).

Meanwhile, gaps in sustainable integration emerge in civil engineering, whether aligned with accrediting standards or not. This disparity emphasizes the critical need for more robust tactics in engineering education (Gutierrez-Bucheli et al., 2023). The changing energy economy challenges Petroleum Engineering programs; therefore, updating the petroleum engineering curriculum by increasing content, including renewables, and considering artificial intelligence and machine learning is critical nowadays. It underlines the long-term value of petroleum engineering skills, which are applicable even in low-emission technology, and advises programs as they traverse this changing energy landscape (Al-Shalabi et al., 2023). There were some interesting results in a recent SPE survey examining how the energy transition affects petroleum engineering education. According to the poll, 95% of petroleum faculty members favor curricular modifications prioritizing sustainability and clean energy. Even though the majority support including data analytics, clean energy, and sustainability in the curriculum, many still expressed worries about their level of readiness. They emphasized the need for more opportunities for industry networking (Fahes et al., 2023). On another note, sustainability is crucial in navigating the evolving Energy Internet landscape in electrical engineering. A recent study suggests a dual-focused curriculum reform to embed sustainability, better equipping engineers for this transformative phase (Zhang et al., 2023). Consequently, a significant storyline emerges, calling for reforming organizational culture within institutions to promote sustainability (Konst et al., 2022). Bridging the gap between institutional beliefs and activities toward sustainability creates a critical narrative that calls for additional research in climate change education (Hindley, 2022).

Amidst these challenges, ongoing efforts at the Australian University in Kuwait strive to integrate CDIO standard #1 on Sustainable Development throughout its engineering program. This ensures students develop solutions focusing on social, economic, and environmental responsibility, preparing them to address complex sustainability challenges in their engineering practices. The fundamental principles of the CDIO approach include four phases. For the "Conceive" phase, the students are encouraged to identify and understand real-world problems by developing a deep understanding of the problem context while considering constraints and defining the scope of the engineering challenge. Regarding the second phase, "Design", the students are engaged in the design process by applying the previously acquired theoretical knowledge to develop an innovative solution for a problem. After that comes the implementation phase, where the students turn their design into a tangible prototype or a working model, which allows the students a hands-on experience to apply the acquired engineering principles and gain practical experience. For the last phase of this approach, which is the "Operate", the students will observe the performance of their design through testing and operating the implemented solution, which in turn will allow them to perceive the effect of their engineering decisions.

Consequently, the CDIO strategy emerges as a transformative force in this educational context since it represents a promising shift from traditional techniques, stressing hands-on, real-world learning. This is a critical framework for engineers tackling sustainability and climate change challenges. This paper contends that the CDIO approach, underscored by its emphasis on real-world application and practical problem-solving, holds promise in dynamically reshaping engineering education. The case studies presented herein serve as a testament to the efficacy of this approach in fostering skill development and acquiring new learning outcomes beyond



the confines of traditional curricula.

## INTEGRATION OF SUSTAINABILITY AND CLIMATE CHANGE: CASE STUDIES FROM THE AUSTRALIAN UNIVERSITY IN KUWAIT

The Bachelor of Engineering Technology curriculum at the Australian University in Kuwait contains three Project-Based Learning (PBL) courses offered in the program's 4th, 5th, and 6th semesters to complement the acquired fundamental knowledge received before or during each PBL course. Each PBL course consists of 75 hours and is worth 3 credits towards the completion of the program. The learning outcomes of these courses are summarized in **Table 1** below:

Table 2. Anticipated Learning Outcomes for the Project-Based Learning Courses

| Level                         | Learning Outcomes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Project 1 (PBL)<br>Semester 4 | LO1. Recall required engineering and sustainability principles to solve well-defined real-world engineering project.<br>LO2. Analyze well-defined project specifications for efficient technical and financial breakdown of the project.<br>LO3. Design and develop a solution that is compliant with the required standards and practices.<br>LO4. Iteratively evaluate and optimize solutions to improve efficiency and compliance through reflection.<br>LO5. Practice project management, oral and written communication, and teamwork skills effectively.                                                                                                                                                                                               |
| Project 2 (PBL)<br>Semester 5 | LO1. Acquire required engineering and sustainability principles to solve well-defined real-world engineering project.<br>LO2. Evaluate and analyze project specifications to organize and prioritize project tasks effectively, considering technical, environmental, and economical aspects.<br>LO3. Synthesize compliant solutions that meet high standards and best practices in engineering.<br>LO4. Critically assess and refine engineering solutions through iterative evaluation to maximize efficiency and ensure robust compliance.<br>LO5. Manage project workflows and lead teams, facilitating high-level oral and written communication and collaboration.                                                                                     |
| Project 3 (PBL)<br>Semester 6 | LO1. Compile diverse engineering and sustainability principles to solve a broadly defined real-world engineering project.<br>LO2. Critically dissecting and integrating project specifications with industry trends and forecasts, integrating technical, environmental, and economical aspects of the project.<br>LO3. Develop sustainable engineering solutions in compliance with the highest industry standards and ethical practices.<br>LO4. Critically evaluate and assess outcomes through reflective thinking for optimal performance and compliance.<br>LO5. Develop a holistic project management approach by mastering leadership, collaboration, oral and written communication within the team and diverse stakeholders, inspiring innovation. |

In this section, two case studies for two projects in the petroleum engineering program are presented and discussed, in addition to how they contribute to the transformative potential of

CDIO.

### **Case Study 1 - Sustainable Management of Oil and Gas Produced Water**

The main objective of this project was to investigate the sustainable management and valorization of oil and gas produced water in Kuwait, addressing the challenges posed by the disposal of this wastewater because it is considered a significant environmental concern (El Achkar et al., 2024). The students were expected to recall, acquire, and compile the different engineering and sustainability principles to analyze, evaluate, and assess the problem and then develop and design a solution to address this problem.

The project focuses on the long-term management of oil and gas produced water, which is an essential aspect of environmental stewardship in the petroleum industry. In addition, it addresses the environmental concerns of improper disposal, directly aligning with sustainability goals. This shows a clear integration of sustainability and climate change perspectives embedded within this course. The project also integrates novel aspects into traditional engineering education by investigating cutting-edge treatment technologies and specific practices used in Kuwait for producing water management. It exemplifies the adaptability of the CDIO approach in incorporating contemporary environmental challenges into engineering curricula.

**Table 2** below summarizes the contributions of such projects to the transformative potential of the CDIO approach.

Table 3. Contribution of the 1<sup>st</sup> Case Study

| <b>CDIO Approach</b>    | <b>Contribution</b>                                                                                                                                                                                                                                                                                                                                           |
|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>C - Conceiving</b>   | As a part of the problem identification and holistic understanding, the students are expected to better understand the problem's scope by defining and characterizing produced water, discussing its composition, and highlighting potential environmental impacts. This is consistent with the CDIO approach's emphasis on real-world problem understanding. |
| <b>D - Designing</b>    | The exploration of treatment technologies by investigating treatment technologies worldwide and those used in Kuwait gives students a broader perspective on available solutions and limitations. This investigation highlights the CDIO approach's emphasis on experimenting with various solutions.                                                         |
| <b>I - Implementing</b> | Considering the Energy-Water-Food Nexus when valorizing produced water to demonstrate a multidisciplinary approach, the students are encouraged to think outside the box and look for new ways to use a waste stream, which aligns with the CDIO approach's emphasis on practical applications.                                                               |
| <b>O - Operating</b>    | The Hands-on experimental evaluation and analysis, such as assessing methane production via anaerobic digestion, requires hands-on application and observation. This is consistent with the CDIO approach's principle of learning through practice.                                                                                                           |

The sustainable management of oil and gas produced water case study demonstrates the CDIO approach's transformative potential in several ways. It actively incorporates sustainability considerations into engineering education and addresses real-world environmental challenges. This case study embodies the essence of a flexible, adaptable educational framework like CDIO by engaging students in problem identification, exploring

diverse solutions, and conducting practical experiments related to sustainable development and climate change.

### **Case Study 2 – Sustainable Liquefied Natural Gas (LNG) Production Process**

The main objective of this project was to examine the liquefied natural gas (LNG) production process, encompassing its significance within the energy industry, the intricacies of LNG liquefaction, factors influencing production, and its environmental impact. The students were expected to calculate the carbon footprint of LNG production after designing and simulating the LNG process using simulation software based on collected data from multiple sources, including industry databases and equipment manufacturers. In addition, the students were expected to explore carbon offset strategies such as reforestation projects, carbon capture and storage (CCS) technologies, and investments in renewable energy while assessing the feasibility of adopting cleaner energy sources to ensure a more sustainable future for LNG production.

The goal of integrating sustainability and climate change perspectives was directly addressed by the LNG project, which thoroughly investigates the environmental impact of LNG production, quantifies the carbon emissions, examines carbon offset strategies, and evaluates cleaner energy alternatives. This project also illustrates the adaptability of the CDIO approach and how traditional programs can evolve to include sustainability and climate change perspectives by involving students in evaluating environmental impacts and proposing sustainable solutions within LNG production. **Table 3** below summarizes the contributions of such projects to the transformative potential of the CDIO approach.

Table 4. Contribution of the 2<sup>nd</sup> Case Study

| <b>CDIO Approach</b>    | <b>Contribution</b>                                                                                                                                                                                                                                                                                                                                 |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>C - Conceiving</b>   | Analyzing factors influencing LNG production and evaluating cleaner energy alternatives necessitates a comprehensive understanding, a hallmark of the CDIO approach's focus on "Conceiving and Designing." This multifaceted analysis cultivates a mindset in which students consider various parameters when addressing sustainability challenges. |
| <b>D - Designing</b>    |                                                                                                                                                                                                                                                                                                                                                     |
| <b>I - Implementing</b> | The project immerses students in real-world problems, consistent with the CDIO approach's emphasis on practical problem-solving. Students gain hands-on experience addressing sustainability concerns by calculating carbon footprints and exploring mitigation strategies, an essential aspect of "Implementing and Operating" within CDIO.        |
| <b>O - Operating</b>    |                                                                                                                                                                                                                                                                                                                                                     |

The project's emphasis on current industry practices and environmental impact directly relates to real-world issues. By incorporating this into the curriculum, the CDIO approach demonstrates its ability to adapt to industry needs while addressing pressing global concerns explaining the framework's relevance. In addition, this project initiates a paradigm shift in education by incorporating sustainability into a traditional engineering program. It exemplifies the CDIO approach's transformative potential in reshaping engineering education by adapting traditional curricula to align with contemporary global challenges.

The CDIO approach actively integrates sustainability and climate change perspectives into traditional engineering education. By engaging students in practical problem-solving, holistic analysis, and real-world applications within LNG production, this project embodies the essence

of a forward-thinking, adaptable educational framework like CDIO.

### ***Discussion on the Two Case Studies***

Those two studies demonstrate how the CDIO approach can integrate sustainability and real-world problem-solving into engineering education. It enriches students' educational experiences and provides real solutions to major environmental concerns, demonstrating this teaching methodology's revolutionary potential. The above-mentioned case studies from the petroleum engineering program at the Australian University in Kuwait demonstrate this transformative capacity since they propelled students beyond conventional boundaries via Project-Based Learning (PBL).

One study addressed sustainable petroleum-produced water management within the Energy-Water-Food Nexus, a cross-disciplinary investigation not typically included in engineering education. This study not only aligns with SDG 6 (Clean Water and Sanitation) by addressing water-related challenges, but it also broadens students' understanding of other SDGs, such as SDG 7 (Affordable and Clean Energy) by emphasizing sustainable energy practices and SDG 13 (Climate Action) by emphasizing carbon-reduction strategies.

Similarly, research into Liquefied Natural Gas (LNG) production covers a wide range of topics, including SDG 7 (exploring cleaner energy alternatives) and SDG 13 (integrating strategies to reduce environmental impact). Furthermore, this interdisciplinary project fosters innovative thinking, which aligns with SDG 9 (Industry, Innovation, and Infrastructure), and exposes students to broader global challenges, developing a holistic approach to sustainability in engineering.

These experiences demonstrate how the CDIO approach goes beyond traditional education, preparing future engineers to address multifaceted challenges across multiple SDGs, where the students learn about sustainability and how to achieve these goals by incorporating diverse aspects into their problem-solving approaches by participating in interdisciplinary projects and understanding the Energy-Water-Food Nexus. This incorporation into traditional engineering programs reflects the CDIO approach's efficacy in shaping engineers who can address environmental challenges holistically, fostering innovation, and achieving the United Nations' sustainable development goals.

## **PROJECT-BASED LEARNING: FUSING VERTICAL AND HORIZONTAL APPROACHES FOR SUSTAINABILITY IN ENGINEERING EDUCATION**

The vertical and horizontal approaches can be used to integrate sustainability into engineering education (Tasdemir and Gazo, 2020). In the vertical approach, engineering programs could introduce standalone subjects or specializations exclusively focused on sustainability. These will offer students a broad understanding of sustainability's core principles, practices, and implications within the engineering setting. For instance, subjects may involve sustainable energy systems, environmental impact assessment, or green engineering solutions. These specialist courses enable students to delve extensively into sustainability issues, gaining expertise and a nuanced grasp of specific sustainability challenges. However, the vertical approach may confront challenges in transdisciplinary learning. Students could thrive in sustainability-specific knowledge but perhaps miss linkages to larger engineering fields. This compartmentalized structure could impair the comprehensive vision for addressing complicated, real-world situations.

In contrast, the horizontal approach incorporates sustainability concepts into existing engineering modules rather than segregating sustainability into separate disciplines. This approach incorporates sustainability principles within standard engineering curricula. Projects in subjects such as structural engineering or materials science, for example, may integrate sustainable design considerations or investigate environmentally conscious materials. This integration enables students to grasp how sustainability intersects with crucial engineering fields, creating interdisciplinary relationships. However, the horizontal approach may provide breadth at the sacrifice of depth. While students obtain a broad awareness of the application of sustainability across engineering fields, the concentration on individual sustainability themes may be less detailed than in dedicated sustainability courses.

### ***The Role of Project-Based Learning (PBL)***

PBL serves as an interface between these approaches since it provides a hands-on, immersive experience in which students work on projects entirely focused on sustainability in the vertical approach. These projects allow participants to put theoretical knowledge into practice by tackling real-world sustainability issues and cultivating specialized skills. PBL's horizontal approach (**Figure 2**) effectively integrates sustainability into existing projects or modules since it encourages students to regard sustainability as an intrinsic part of their primary engineering curriculum by including sustainability factors in traditional engineering projects, such as eco-friendly design considerations or renewable energy applications. This approach fosters multidisciplinary thinking by integrating sustainability themes with multiple engineering fields.

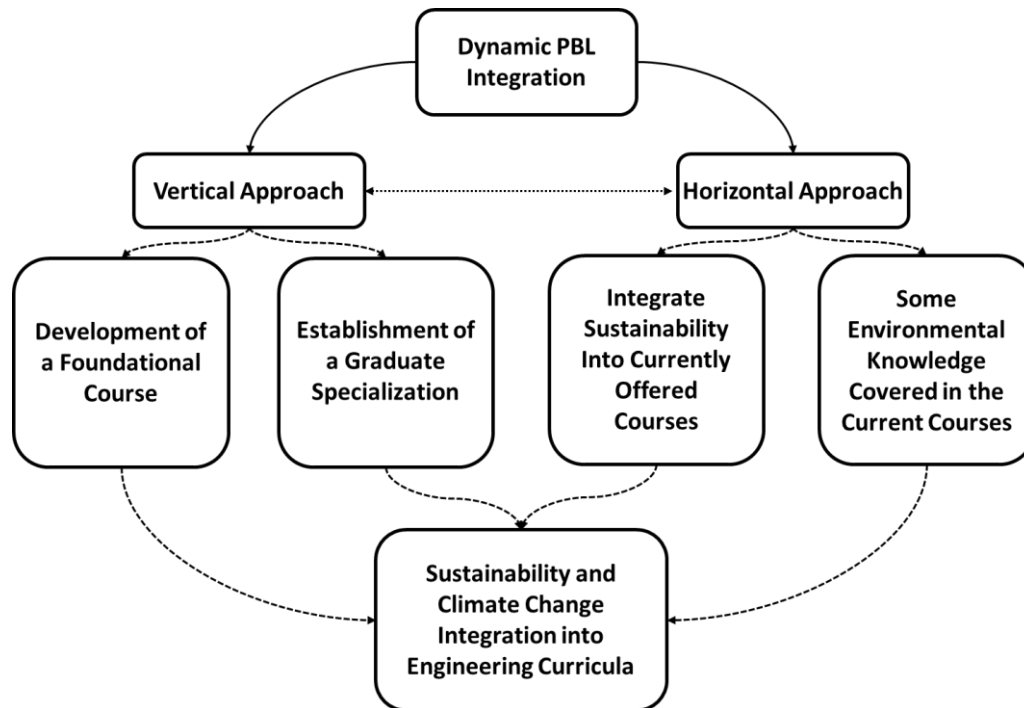


Figure 3. Integration of Sustainability in Engineering Curricula: A PBL Bridge between Vertical and Horizontal Approaches

Overall, PBL encourages students to connect meaningfully with sustainability when thoughtfully integrated into both vertical and horizontal approaches. In addition, it provides a pathway for students to comprehend, apply, and innovate sustainable solutions, thereby contributing to a comprehensive understanding of sustainability and its role in addressing

global challenges within engineering curricula, whether through dedicated sustainability projects or infusing sustainability into traditional engineering modules.

### ASSESSMENT OF KNOWLEDGE AND PERCEPTION: PRE AND POST INTEGRATION OF SUSTAINABILITY IN ENGINEERING CURRICULA THROUGH PBL

During the academic year 2022-2023, a set of five questions, with ratings ranging from "Very Low / Poor" at 1 to "Very High / Excellent" at 5, were asked to 40 participating students enrolled in the PBLs mentioned above to quantify the perceived changes in understanding, awareness, and applicability of sustainability and climate change concepts before and after the PBL project, enabling a comparative analysis of students' perspectives. The survey results were analyzed using statistical measures such as average and standard deviation to ensure clarity and reliability.

The tables below summarize the results of the two surveys administered to students to assess the integration of sustainability principles into engineering education via PBL. The surveys aimed to examine students' initial perceptions and understanding of sustainability concepts (**Table 4**) and assess the impact of the PBL integration on their knowledge and perceptions (**Table 5**).

Table 5. Pre-Survey Results on Sustainability Integration in Engineering Education

| PBL Pre-survey                                                                                                                                                                    | Avg. Students' Rating (Scale of 5) |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|
| Knowledge: On a scale of 1 to 5, how would you rate your current understanding of sustainability principles and their application in engineering projects?                        | 2 ± 0.2                            |
| Awareness: Rate your familiarity with the relationship between engineering practices and their impact on climate change from 1 to 5.                                              | 2 ± 0.4                            |
| Perception of Sustainability Integration: On a scale of 1 to 5, how well do you feel your engineering education covers sustainability and climate change?                         | 2 ± 0.4                            |
| Previous Exposure: Rate from 1 to 5 based on your previous engagement with coursework or projects explicitly addressing sustainability or climate change in engineering contexts. | 2.5 ± 0.3                          |
| Expectations: Rate your expectations for gaining knowledge or skills through the upcoming PBL project integrating sustainability into engineering curricula from 1 to 5.          | 3 ± 0.3                            |

Table 6. Post-Survey Results on Sustainability Integration in Engineering Education

| PBL Post-survey                                                                                                                                            | Avg. Students' Rating (Scale of 5) |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|
| Knowledge: How much has your understanding of sustainability principles improved after completing the PBL project? Rate from 1 to 5.                       | 4 ± 0.1                            |
| Understanding: Has the PBL project enhanced your knowledge of the link between engineering practices and their impact on climate change? Rate from 1 to 5. | 4 ± 0.2                            |
| Impact: Rate from 1 to 5 how the PBL project contributed to your knowledge of sustainability and climate change in engineering contexts.                   | 4 ± 0.3                            |

|                                                                                                                                                                                                                     |           |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| Perceived Relevance: Do you believe that integrating sustainability through PBL has increased the relevance of sustainability concepts in your engineering education? Rate from 1 to 5.                             | 4.5 ± 0.3 |
| Application of Knowledge: How confident do you feel in applying sustainability principles and considering climate change factors in future engineering projects after completing the PBL project? Rate from 1 to 5. | 4 ± 0.1   |

The tables analyze students' pre-survey responses to specific questions about prior knowledge, awareness, perceptions, and expectations. This data is contrasted with the comparable post-survey results, demonstrating the shifts in students' understanding, awareness, and perceived importance of sustainability concepts after participating in the PBL effort. Before PBL, students understood engineering sustainability ideas poorly. Their baseline knowledge, climate change comprehension, and engineering curriculum sustainability were rated 2 out of 5. Even though they had taken sustainability classes, they were cautiously optimistic about the next PBL project.

Post-survey findings showed a considerable improvement. Students reported significant gains in all areas after the PBL assignment, and their sustainability knowledge improved from 2 to 4. Their grasp of the relationship between engineering practices and climate change and the implementation of sustainability concepts in engineering education improved to 4 out of 5. PBL integration made sustainability topics seem relevant, which was remarkable. Students rated sustainability as more important in engineering education at 4.5 out of 5. This indicates that the PBL approach successfully combined sustainability principles with engineering methods, making them more applicable to their area. Post-PBL integration improvements showed that hands-on, project-driven learning improves engineering students' understanding and appreciation of sustainability. The substantial positive shift in perceptions and knowledge highlights the potential of Practical learning methods like PBL in developing a more holistic and environmentally responsible approach within engineering curricula.

## CONCLUSIONS AND PERSPECTIVES

To conclude, PBL acts as a bridge, allowing students to connect profoundly with sustainability in various ways. It facilitates the comprehension, application, and creativity of sustainable solutions, fostering a complete awareness of the role of sustainability in engineering education. The change in students' attitudes following PBL highlights the importance of hands-on, project-driven learning in creating a more holistic and environmentally conscious approach among engineering students.

Several critical perspectives are positioned to affect future sustainability integration into engineering education. It is essential to emphasize interdisciplinary collaboration across varied sectors, fostering holistic problem-solving skills for addressing complex sustainability concerns. Equally important is equipping educators with comprehensive sustainability pedagogy training, ensuring seamless course integration. Strengthening linkages with industries engaged in sustainable practices is vital, providing students with real-world project experiences that integrate academic understanding with practical applications. Continuous curriculum evaluation and enhancement are required to ensure relevance and innovation in adapting to evolving sustainability paradigms. Fostering worldwide collaborations and information exchange programs also broadens perspectives, enabling a better understanding of various sustainability scenarios. This multidimensional approach is crucial for successfully integrating sustainability into engineering education, and PBL appears to be a key tool for

influencing future engineers' mindsets and establishing a strong commitment to addressing global sustainability concerns.

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# **CHALLENGE-BASED LEARNING: IDENTIFYING EXTRACURRICULAR STUDENT TEAMS' DISCIPLINARY LEARNING GAINS**

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## **ABSTRACT**

The purpose of this study is to gain new insights into the disciplinary learning gains that students acquire after finishing their participation in engineering-oriented extracurricular student teams. Making these learning gains explicit has the capacity to nurture students' professional identities and enhance their employment prospects in the job market. This study involved conducting group sessions with members of two student sub-teams, both part of one overarching team. Results indicate that students acquired learning gains associated with the hardware manufacturing process, disciplinary design, multidisciplinary design, and utilization of knowledge. Additionally, students reported that they developed learning gains by means of interacting with peers, participating in workshops, and consulting various experts.

## **KEYWORDS**

Extracurricular, Student Teams, Challenge-Based Learning, Learning gains.  
CDIO Standards 1,2,3,4,5,7,8,11,12.

## INTRODUCTION

Extracurricular learning holds the potential to positively shape students' professional identities and expand their awareness of future career opportunities. To effectively guide students in recognizing and capitalizing on their extracurricular learning, higher education institutions must support students in explicitly articulating these gains (van Uum & Pepin, 2022). However, this task is challenging due to the highly open and self-directed nature of learning in the extracurricular context.

Literature has informed us that students engaged in engineering-oriented extracurricular teams develop competencies emphasized in engineering education, such as specified in the CDIO syllabus (Bravo et al., 2023). Examples of these competencies include personal and interpersonal skills such as initiative, self-awareness, self-confidence, teamwork, and communication (Clark et al., 2015; Larson et al., 2006; Stuart et al., 2011). Furthermore, scholars have emphasized additional benefits relevant to the skills and competencies sought after by the engineering job market and necessary for starting companies, such as enhanced management and organizational skills (Thomson et al., 2013). Additionally, literature has highlighted the development of social networks and improved job market prospects, which are crucial for students' future career success (Stuart et al., 2011). Nonetheless, limited research exists on disciplinary learning gains within the context of extracurricular student teams addressing socio-technical open-ended challenges where students are in the lead of the project. This study seeks to acquire new insights on the learning experiences of students involved in extracurricular engineering-oriented student teams and their contribution to the acquisition of disciplinary learning gains.

## THEORETICAL FRAMEWORK

Qualitative insights into perceived changes in students' learning can offer relevant insights to both students and higher education institutions regarding the value of participating in engineering-oriented extracurricular teams. To capture these insights, we must initially establish a clear definition of what constitutes a change in learning, i.e. a learning gain.

Pampaka et al. (2018) suggested that a learning gain is what is learned between two or more time points. In a more detailed definition, McGrath et al. (2015, p. xi) define learning gain as *"the 'distance travelled,' or the difference between the skills, competencies, content knowledge, and personal development demonstrated by students at two points in time. This allows for a comparison of academic abilities and how participation in higher education has contributed to such intellectual development."* In this study, the definition proposed by Vermunt et al. (2018, p. 272) was chosen because it allows to capture the diverse types of changes in learning that can be acquired during the participation in an extracurricular engineering-oriented student team. They define learning gain as *"a student's change in knowledge, skills, attitudes, and values that may occur during higher education across disciplines."*

Various methods assess students' learning gains, including empirical observations, surveys, rubrics, and self-report questionnaires. Self-reports foster self-reflection and enhance learning by promoting self-monitoring habits. However, relying solely on self-reports has limitations, such as potential overconfidence in knowledge and subjective comparisons of perceived learning gains. In this study, we utilized self-reports because our emphasis is on the process explanations for students' acquisition of learning gains and their types rather than the depth of the learning experience.

In this study, the CDIO Syllabus Revision 3.0 was chosen as the framework for conducting thematic analysis of students' self-reported learning gains for two primary reasons. Firstly, the CDIO syllabus provides comprehensive descriptions of learning outcomes across fundamental knowledge, personal and professional skills, interpersonal skills, and the innovation process. Secondly, the expansion section describes learning outcomes associated with leading engineering endeavors, entrepreneurship, and research (Malmqvist et al., 2022). These elements aids in categorizing what students self-report regarding their extracurricular experiences given the characteristics of extracurricular projects undertaken by student teams at TU/e and TU/e innovation Space's focus on fostering expertise in technology-based innovation and entrepreneurship.

## **CONTEXT OF THE STUDY**

TU/e innovation Space is the center of expertise for student entrepreneurship and challenge-based learning (CBL) at Eindhoven University of Technology. In CBL, students tackle real-world challenges as teams. They have the freedom to design and direct their own projects, which fosters self-directed learning. This approach empowers students to acquire the necessary knowledge and skills for successful problem-solving (Doulougeri et al., 2021).

TU/e innovation Space student teams program provides support to approximately 650 students who participate in extracurricular teams to address global socio-technical challenges in collaboration with external entities such as companies, societal organizations, and research institutes. These teams are heterogeneous, including members from various academic programs, educational levels, and nationalities. Their commitment varies, depending on personal availability and motivation. Teams shape their organizations to reach unique goals. Their technological projects cover a wide spectrum, ranging from technological divulgation to the development of cutting-edge technology. One of the most important drivers is students' intrinsic motivation. Furthermore, participation is voluntary, stimulated by a shared sense of purpose. Finally, TU/e innovation Space provides coaching, technical expertise, physical infrastructure, and counsel on financial and legal aspects.

Teams are structured based on sub-teams that handle specific tasks that can be, among others, technical, managerial, communicational, etc. The objective of the sub-teams is to work effectively. It implies that members acquire specific knowledge, attitudes, skills, and competences that help the team reach its goals. The sub-team is the basic work cell that contributes to achieving the overarching goals. Furthermore, team knowledge and experience are developed and contained in these units, and from there they are spread across the team.

## **RESEARCH QUESTIONS**

In this study, we are interested in the types of learning gains that the students acquire and the processes that enable them. Therefore, the study addresses the following two research questions: Q1) What disciplinary learning gains do students acquire during their participation in an extracurricular engineering-oriented student sub-team? Q2) How do students develop these disciplinary learning gains?

## **METHODOLOGY**

### ***Participants***

In this study, a volunteer student team named Ice (pseudonym), took part. Its goal was to design, build, and test a solar-powered, self-driven Antarctic research rover (See Appendix A). Two of its sub-teams participated in this study. These were: Nomad sub-team, comprising four members, all part-time, with a background in mechanical engineering, was tasked with the design and construction of the rover's chassis. They were responsible for integrating components designed and built by other sub-teams. They resolved interface issues, such as determining how to securely attach solar panels to the chassis or finding suitable space for installing batteries and cables. In addition, they were responsible for ensuring the structural integrity and functionality of chassis components. Transmission sub-team, comprising of three part-time members with backgrounds in electrical and mechanical engineering, was focused on capturing, storing, and transmitting energy to the rover's transmission. Students selected batteries and ensured the energy delivery to the transmission. Also, this sub-team encountered challenges in maintaining optimal battery temperature and preserving the efficiency of the solar panels. They were also tasked with addressing interface requirements with the chassis and control electronics.

### ***Data collection***

This study focused on collecting teams' insights regarding learning gains during a 90-minute artifact analysis workshop. The workshop was audio recorded and commenced after participants had given their consent to participate. During the workshop, sub-teams engaged in reflection on the systems and components they had designed and constructed. These artifacts were utilized throughout the workshop to enrich the discussions.

To facilitate further, a purpose-designed board with three sections—triggering factors, critical steps, and learning gains—was used (see Appendix A). In the first section, triggering factors, students detailed what they wanted to know and the knowledge they previously had to address the project technical challenges. In the second section, critical steps, participants explained the process they followed to achieve the project's goals. Participants also recounted learning events and identified means that supported their learning, adding depth to their understanding of the process. Finally, participants identified the learning they acquired through their participation in the sub-team. Students used post-its, notes, drawings, or artifacts to provide more details.

## **DATA ANALYSIS**

The data obtained from the artifact analysis workshops were analyzed focusing on coding students' quotes related to learning gains. This iterative process involved refining the code list, incorporating new codes, and adjusting the coding strategy. The initial step involved reading the entire dataset without applying any codes to gain a comprehensive understanding of the data. Learning gains were considered only when students explicitly mentioned gaining insight into their performance or mastering competences, following a methodology similar to Bakkenes et al. (2010).

Learning gains were coded and classified according to the main categories established in CDIO syllabus 3.0. These are: fundamental knowledge and reasoning; personal and

professional skills and attributes; interpersonal skills; the innovation process; and leading engineering endeavors.

## RESULTS

The following paragraphs detail the insights shared by both sub-teams during the sessions. We first described what the sub-teams learned and then how the sub-teams learned.

### ***What students learn***

Nomad sub-team wanted to learn how to increase the modularity and stability of the chassis. It involved working with diverse materials and integrating engineering knowledge to enhance functionality. The team also wanted to learn how to transform raw materials into purposeful components. Finally, they wanted to learn how to use power tools.

The sub-team members indicated that they entered the project with an understanding of the content covered in the first-year mechanical design course and the experience of designing and building a model crane using L-shape steel profiles for its structure.

Upon reflecting on the processes carried out by Nomad sub-team, members articulated significant learnings. First, they emphasized that they learned the importance of thoughtful consideration before implementation (Innovation process: Consideration of implementation and operation), underscoring a key takeaway: they learned the relevance of the conscious evaluation of how potential implementations of components or subsystems can influence the overall vehicle functionality. For example, students indicated the cooling system critical event:

*“When the motors finally got working, they ran at like max speed for half an hour. And they got up to 90 degrees. Which is pretty warm. Especially when they are in a closed capsule. So then someone said, You should have a cooling system. And okay, we should make a cooling system. The only thing we could think of was air cooling.”*

To address this challenge the students decided to implement some vents in the back and the front of the chassis to allow air circulation to cool the electronic components. After the implementation of the solution, they become aware of its impact. They indicated:

*“Then we said, oh no, we have holes in our vehicle. After some thinking, we realized that it’s not that big of a deal if we left hot air inside to get up to like 90 Celsius degrees in such a cold temperature, because of all the cooling snow around. We cut those holes for nothing and we spent a lot of time trying to come up with ways of ensuring that air can get through, but water can get through too. That was definitely an experience that we had to have. So, definitively, we learned.”*

Contrary to the initial assumption of a linear design and implementation process, the sub-team discovered that the design process is iterative and involves, among others, observation, reflection, analysis, and actions such as prototyping and performing calculations. (Innovation process: The design process phases). At the beginning, the students indicated that when they had an idea, they just implemented it in the vehicle, and then they analyzed if the idea produced the results they expected. Student B indicated that for a lot of parts of the vehicle they just implemented design and construction actions and afterwards they thought about its impact.

However, after several situations where they didn't achieve the expected results, they became aware of the importance of analyzing the solution implications in other components. In this regard, they indicated:

*“There was a moment when we just stopped and thought for a second. it was really like, we should really make some calculations because we know this!, and that helped out quite a bit. If you want to stop the bending chassis we have to use the L profile, because it stops the momentum...and we knew the physics behind it”*

In addition, the team found value in integrating learning experiences such as the ones from their first design-based learning course (Innovation process: Utilization of knowledge in design). Students expressed awareness of the fundamental principles of solid mechanics governing the behavior of a steel L-shape profile. Consequently, they opted to assemble these profiles in a manner that optimizes their mechanical properties, particularly in terms of resisting torsion and flexion, thereby ensuring the structural integrity of the chassis.

Also, connected to the implementation of the L-shape profile chassis, the sub-teams indicated that they gained proficiency in the use of metal-mechanical tools (Innovation process: Hardware manufacturing).

The interconnectedness of diverse elements within the project became evident, prompting a broader perspective on system integration. The realization that systems are integral parts of a larger whole underscored the importance of considering the broader context in problem-solving and decision-making (Innovation process: trade-offs among various goals, function, concept, and structure). In this regard, student A expressed:

*“So, if you really want to make this aerodynamic, then you would make it really small like it basically looks like a bullet. But then how do you fit some of the stuff inside? Same thing with making it structurally stable. You would make it out of pure steel, like no sandwich boards. But then you just sink into the snow. So there's some optimal weight...and that's kind of the fun part of trying to figure out where that is and what we would sacrifice for it.”*

In the case of the Transmission sub-team, its members expressed that they wanted to learn about electric mobility. Specifically, they expected to learn about how electric transmission components are made and how the power is controlled when transmitted to the wheels. In addition, the students expressed they wanted to learn how to capture, store, and distribute electricity in a solar vehicle. Lastly, the sub-team emphasized that they wanted to acquire practical technical knowledge on hardware manufacturing.

Students reported that they knew some information about Antarctica's site conditions. They highlighted factors such as temperature range, humidity levels, and variations in sunlight hours throughout the year. Moreover, they had a basic understanding of how these environmental variables influence the design requirements for the rover, such as the necessity for sustainable energy usage and the implications of temperature and light exposure on the battery system. Additionally, they expressed a basic knowledge of electric powertrains, based on both their coursework in mechanical engineering and supplementary information from online sources.

The students reported that after their participation in the sub-team, they acquired learning gains in several sub-categories of the CDIO syllabus. Regarding the manufacturing process, they indicated that they acquired knowledge and experience in new soldering techniques for

electrical cables and also learned about electrical cable physical restrictions (Innovation process: Hardware manufacturing). For example, student C indicated the following:

*“We learned about how the slack of a cable could be very useful at times. We had a too-tight cable. And later, because we wanted to make the backplate stronger, we put an iron bar on it to enhance it. What happened was that this slack of the cable was gone at that point, because now there was a bar pretty tight. And what happened was that, at some point, because of the bar, the cables broke completely. So we learned that slack is important.”*

In addition, they reported learning gains associated with increased understanding of the design process and its stages (Innovation process: Design phases). For instance, the students indicated:

*“The process of designing or building something begins with initial research and ideation, mapping out the entire process from concept to product. I've personally experienced this entire process multiple times, acquiring a good understanding of how to progress from an idea to the final product in a structured manner.”*

Also, they indicated that they became aware of the relevance of the design process and the relevance of the purpose of the design (Innovation process: The design process)

*“I think we learned the importance of researching and designing, which was sometimes skipped a little bit and let the first solution be taken, and then we discovered that it didn't really work.”*

Finally, they indicated that they acquired new engineering knowledge about energy storage systems, which was not part of the contents covered by sub-team members previous courses (Fundamental knowledge: Engineering knowledge) and also gained awareness on avoiding overengineering components and systems (Innovation process: Requirements of elements and components). Student D indicated:

*“The simple thing works the best, and don't overengineer or overcomplicate things; don't look for this shiny way of doing things.”*

### **How they learn**

In order to answer the second research question, both teams were asked to describe the process they followed to achieve their goals. Students indicated that company advisors, external advisors who belong to research institutes both internal and external to the TU/e, technical advisors from TU/e innovation space, and peers influenced their acquisition of learning gains. These resource persons transferred technical knowledge, experiences, and they provided feedback on design and implementation aspects, specifically materials, manufacturing process, and technical aspects on the site conditions in Antarctica. For instance, student A, from the Nomad sub-team, chassis, indicated that they received advise from an architect who works in a research facility in the Antarctica:

*“So he has a lot of knowledge about the building, but also about the site conditions. When we were talking about thermodynamics, he was very knowledgeable about the way the station works—it is abandoned in winter. So we have to make sure that all the core systems stay alive during the winter months. They put things in the*



*middle of the physical center of the station because it takes longer for that to cool down. And just things like that are also something that's a huge resource that experts have."*

In addition, both teams indicated that they followed different approaches to address project's challenges and consequently to acquire learning gains. Based on the sub-teams' reports, different work processes were executed depending on the system they had to design, manufacture, and test. For example, Nomad sub-team indicated that they follow a trial and error approach when finding the right structural stability once the solar panels were installed on the chassis. Students indicated that due to their time restrictions they didn't have the time to think in a detailed way about the solution:

*"It was a trying solution; It is one of those systems where you could add more to it because we were just reinforcing."*

Transmission sub-team followed a different approach that included first researching, ideating, integrating previous knowledge, and then testing. After observing the results, they took corrective actions, in the case the results were not satisfactory, and then they tested again.

## **DISCUSSION**

The insights gathered from the sub-teams show the diverse learning gains acquired throughout the project's duration. Nomad sub-team reported learning gains associated with the innovation process. Their recognition of the significance of thoughtful consideration before implementation represents a substantial realization. This strategic perspective emphasized the crucial role of pre-implementation evaluation in shaping overall vehicle functionality. Furthermore, Nomad sub-team's increased acknowledgment of the iterative nature of the design process, involving observation, reflection, analysis, and actions such as prototyping, deepened their understanding of the innovation process. In addition, the integration of experiences from their initial design-based learning course, particularly in applying knowledge to design, demonstrated them a practical application of academic knowledge. Finally, Nomad sub-team increased their awareness of the interconnectedness of diverse elements within the project, prompting a broader perspective on system integration.

Transmission sub-team's increased awareness of the environmental conditions in Antarctica and its technical challenges indicates a proactive approach to project considerations. Their concerns about battery system operation in low temperatures increased the practical understanding of real-world challenges and the need for innovative solutions. Also, they reported learning gains connected to a hands-on approach to hardware manufacturing such as mastering new soldering techniques, understanding electrical cable physical restrictions, and increased insights into the design process stages. Additionally, the acquisition of new engineering knowledge about energy storage systems and awareness to avoid overengineering demonstrate a broadening of their disciplinary learning gains.

The responses provided by both teams shed light on the intricate process through which students develop disciplinary learning gains within the context of their extracurricular engineering-oriented projects. Addressing the second research question (How disciplinary learning gains are developed) reveals a dynamic and collaborative approach influenced by various advisors and peers. In this regard, the involvement of company advisors, external advisors from research institutes, technical advisors from TU/e innovation space, and peers

significantly impacted the acquisition of learning gains. These played a crucial role in transferring technical knowledge, sharing experiences, and providing valuable feedback on design and implementation aspects. The specificity of their contributions, particularly in areas such as materials, manufacturing processes, and considerations related to the challenging site conditions in Antarctica, underscores the multidimensional nature of the learning process.

Furthermore, both sub-teams highlighted the adoption of diverse approaches to address the challenges and, consequently, to acquire learning gains. Nomad sub-team's utilization of a trial-and-error approach, especially in determining the structural stability after the installation of solar panels on the chassis, exemplifies a pragmatic method within the constraints of time. The acknowledgment that detailed thinking might be limited due to time restrictions highlights the need for adaptive problem-solving in real-world scenarios. In contrast, the Transmission sub-team opted for a more systematic approach involving research, ideation, integration of previous knowledge, and testing. This methodical process allowed for a structured examination of results, enabling them to take corrective actions and iterate on their designs when necessary. The emphasis on testing as an integral part of the process aligns with a continuous improvement mindset, reflecting a commitment to refining solutions based on observed outcomes.

## **CONCLUSIONS, LIMITATIONS, AND FUTURE RESEARCH**

In conclusion, both sub-teams exemplify the integration of theoretical knowledge and practical skills within the CDIO framework, showcasing the benefits of challenge-based learning. The recognition of the interconnectedness of elements, iterative design processes, and the application of engineering principles to real-world challenges underscores the richness of the learning experiences within these extracurricular projects performed by student teams.

In addition, the development of disciplinary learning gains among students participating in the sub-teams is a collaborative and multifaceted process. The influence of diverse advisors and peers, who contribute technical knowledge and experiences, highlights the importance of mentorship and collaborative learning. The sub-teams' adoption of varied approaches to address project challenges demonstrates adaptability and problem-solving skills within the constraints of time and resources. In parallel, the two sub-teams used different approaches: the pragmatic trial-and-error approach by Nomad sub-team and the systematic research-ideation-testing cycle employed by Transmission sub-team. Together they showcase the flexibility required in complex engineering projects. These diverse methodologies contribute to a comprehensive learning experience, encompassing both theoretical knowledge and practical problem-solving skills. The findings underscore the significance of experiential learning, and adaptive strategies in fostering the development of students' disciplinary learning gains in real-world engineering challenges. Producing an artefact provided numerous incentives to rethink their approach in solving their challenges.

A limitation of this study arises from conducting the session exclusively with two sub-teams within the same overarching team, constraining the diversity and quantity of learning gains identifiable among students. This limitation extends to the various ways in which students learn within a sub-team. Therefore, it is recommended that future studies involve diverse teams with varying structures, distinct projects in terms of objectives, and unique technical challenges. This approach aims to unveil a broader spectrum of learning gains and diverse approaches for addressing technical challenges, ultimately fostering different methods of acquiring learning

gains. In subsequent studies, we aim to explore how work processes, employed to tackle technical challenges, influence the types and quantities of learning gains acquired by students.

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Appendix A – Sub-team disciplinary learning reflection board and artifact pictures

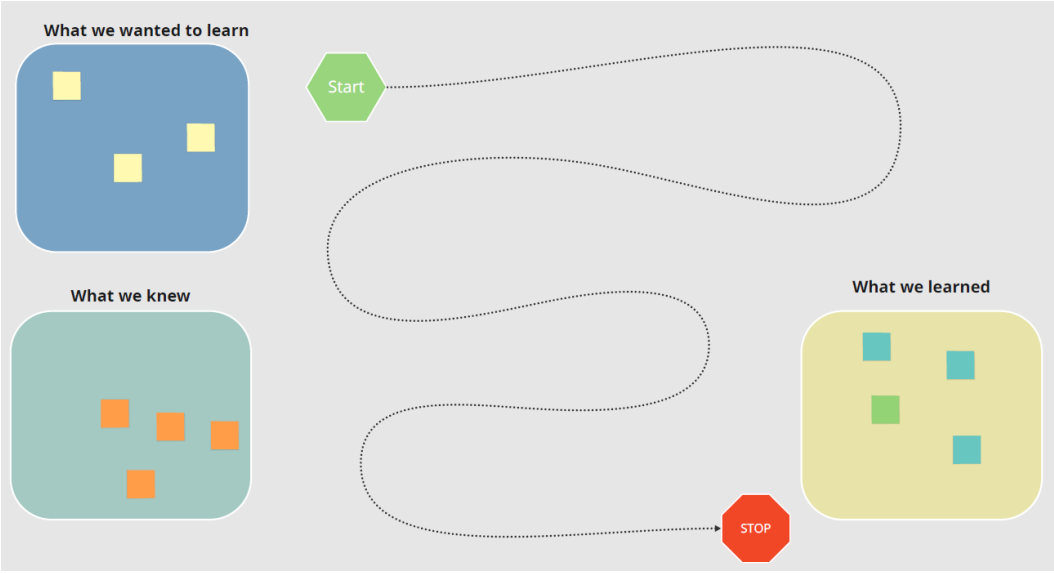


Figure 1. Reflection board

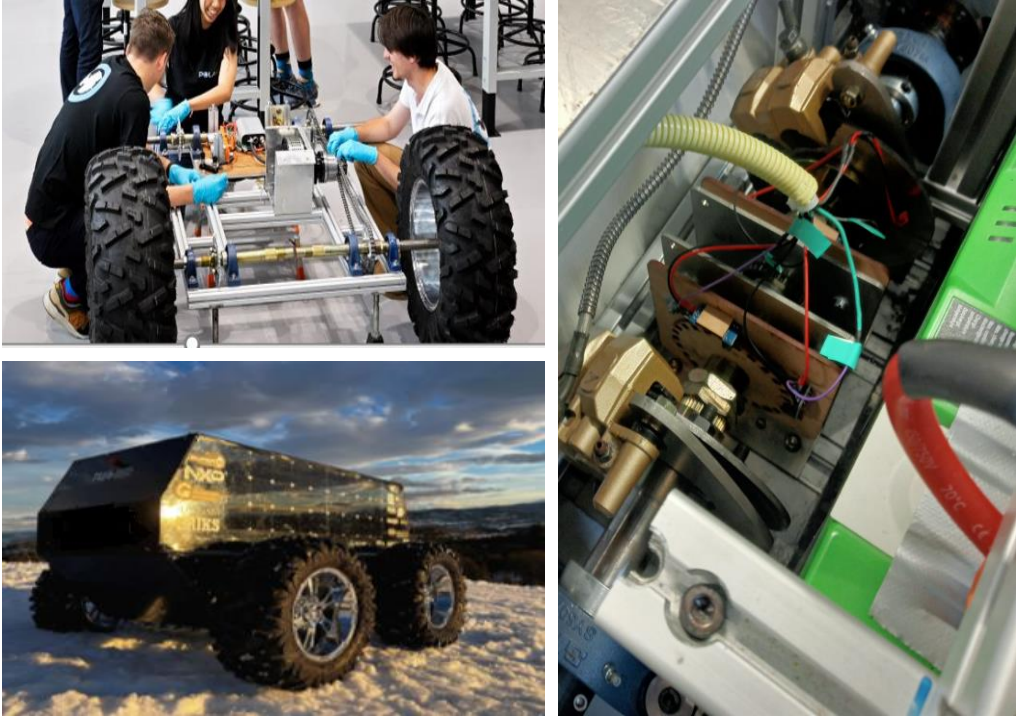


Figure 2. Team Ice's rover

# **FIRST-YEAR ENGINEERING STUDENTS AT REYKJAVIK UNIVERSITY: RELATION BETWEEN CLASS ATTENDANCE AND FINAL EXAM GRADE**

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## **ABSTRACT**

Modern technology, such as online digital tools, enables some students to gain their university degrees without ever attending onsite classes in person. However, showing up in person to classes and interacting with other students and instructors may be beneficial for the students' academic performance in an active learning environment. At the Department of Engineering at Reykjavik University in Iceland, there are around 200 students enrolled in first-semester engineering courses every year. They enroll in 8 different study lines, and all students take the same four courses in the first 12-week autumn semester. The setup of the four courses is similar, all with 4x45 min lectures and 2x45 min tutorials every week. Attendance is not mandatory, but students can increase their course final grade if they attend a minimum number of tutorials on-site during the semester. In this study, a comparison was made to see if there is a relationship between attendance and the final exam grade the students get in the course final exam. The results indicate a positive relationship between these factors where the students receive generally around 10-20 more points (out of 100) in the final exam if they have attended the tutorials well. According to literature, this is generally the tendency for students in other universities, where related studies have been made.

## **KEYWORDS**

Engineering Education, Onsite Attendance, Active Learning, Learning Assessment, Standards: 8, 11

## **INTRODUCTION**

Access to learning materials for university students has changed much in the last few years, and much of the learning materials, lecture material, solutions to assignments, and lecture recordings can be made available online instead of or in addition to the onsite classes. During the pandemic, lecturers at universities had to move much of their activities to online teaching and the possibilities and limitations of online studies became clearer. It is therefore interesting and important to study whether there is a relationship between onsite attendance and academic performance of students. This has been done in a number of studies over the years, as summarized in the literature review in the next section.

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To the author's knowledge, a study comparing attendance and exams among Icelandic university students has not been published. In this paper, data about attendance and final grades among first-year engineering students at Reykjavik University is presented, and the data is analyzed to observe if there is a relationship between the final exam grade and onsite attendance among the students.

## LITERATURE REVIEW

From some previous studies, it has been found that there might be a correlation between student attendance and student academic performance where most of these studies indicate a positive correlation between these two factors (Lukkarinen et al., 2016), (Moore et al., 2003), (Purcell, 2007), (Credè et al., 2010) although other factors like how many credits students are taking, travel time to the university and number of working hours outside the university also play a role in the examination performance (Kirby and McElroy, 2003).

Ulmer (2020) showed a relation between professionalism grades (attendance and punctuality) and final course grades. For students earning 80-100% in the final grade, there was a high professionalism grade (above the average final grade), but the professionalism grade went below the final grade for students earning between 70-80% in the final grade. There was a similar professionalism grade and average final grade for students earning below 70% in the final grade.

With students having increasing access to online learning material and recordings from classes, it is also interesting to see if these tools affect the relationship between attendance (online or onsite) and academic performance. In the study of Nordmann et al. (2019), it was found that students who generally performed better also performed better in courses where they used supplementary recordings instead of attending than students who generally performed worse in their studies. This difference was more prominent in the earlier years of their study. Also, results from the study of Varousa-Sousa and Kingston (2015) indicate that students performed better if they attended lectures onsite than watching recordings. Inglis et al. (2011) showed a negative correlation between the frequency of watching lecture recordings and student performance, which might indicate that students performing worse had to revisit the material more often than the students generally performing better in their studies. Results from a study performed by Williams et al. (2012) show that students who only watched recordings performed worse than those attending onsite. However, students who supplemented onsite attendance with recordings performed better than students who only participated onsite and did not revisit the material through the recordings.

Most of the literature regarding this topic covers traditional lectures and tutorials, but less is known about problem-based courses. Bijmans and Schakel (2018) observed a "noticeable effect of attendance on study success" for three cohorts that were analyzed.

Kirby and McElroy (2016) analyzed the relationship between attendance and grades for first-year economics courses. Their findings show that class attendance had a positive but diminishing marginal effect on student's grades. Obeidat et al. (2012) analyzed course grades regarding GPA, attendance percentage, and number of credits students were enrolled in. According to their findings, attendance percentage strongly affected the grades in a particular course. Lukkarinen et al. (2016) divided the students from a course into three groups based on their attendance and performance and found that attendance was "positively and

significantly related to performance". However, as stated in their literature review, results from some studies do not indicate a positive relation between these factors, whereas Eisen et al. (2015) did not observe that attending classes improved academic performance in their introductory dermatology course.

According to this literature, there is a clear but nontrivial indication that onsite attendance will improve the student's academic performance. To the author's knowledge, a study of this relationship has not been published for Icelandic universities. In order to contribute to this knowledge gap, data for attendance and final grades were gathered from first-year engineering classes at Reykjavik University in Iceland throughout a couple of years and analyzed.

## ENGINEERING STUDY AT REYKJAVIK UNIVERSITY

Reykjavik University in Iceland is a young university that has offered BSc and MSc degrees in engineering since 2005. Around 200 students are enrolled in the first year of undergraduate BSc study every year in seven study lines: Financial Engineering, Engineering Management, Biomedical Engineering, Mechatronics, Energy Engineering, Mechanical Engineering, and Electric Power Engineering. The department has implemented the CDIO approach into its curriculum for more than a decade (Audunsson et al. (2020) and Saemundsdottir et al. (2012)). The setup of the first-year courses is shown in Table 1. All the students take the same courses in the first semester, regardless of which engineering study line they have chosen. The semester is divided into two parts: first, the students take four courses for twelve weeks and then one course for three weeks.

Table 1. Course setup for 1<sup>st</sup> year BSc Engineering students at Reykjavik University

| First semester                                                           | Second semester                                               |
|--------------------------------------------------------------------------|---------------------------------------------------------------|
| Calculus I (6 ECTS)                                                      | Calculus II (6 ECTS)                                          |
| Physics I (6 ECTS)                                                       | Physics II (6 ECTS)                                           |
| Linear algebra (6 ECTS)                                                  | Engineering Programming (6 ECTS)                              |
| Programming in Matlab (2 ECTS)<br>Energy (4 ECTS)                        | Study line specific course (6 ECTS)                           |
| Brainstorming (1 ECTS)<br>Introduction to Engineering (5 ECTS) (3 weeks) | Entrepreneurship and Starting New Ventures (6 ECTS) (3 weeks) |

In this study, data regarding attendance and final exam grades was gathered for all the first-semester courses (see Table 1) except for Programming in Matlab, Brainstorming, and Introduction to Engineering, and data was also collected for the second-semester courses Calculus II and Physics II. The courses that are not included in the study were excluded as they may not have registered attendance or have different attendance policies between study lines.

The Department of Engineering is a part of the CDIO network, and this study pertains to standards 8 and 11 from CDIO Standards 3.0 (CDIO, 2024). Standard 8: Active Learning is incorporated through active learning methods like tutorials where students are working independently as well as in groups where Teaching Assistants (TAs) are supervising their activities in class. Standard 11: Learning Assessment is through diverse methods of assessing the students' performance, like attendance, exams and home assignments.



## DATA COLLECTION AND ANALYSIS

The summary of all the courses that were analyzed for the relationship between attendance and final exam grades in this study is shown in Table 2. Attendance in these courses was only documented for problem classes (tutorials) and not for lectures. Attendance for lectures was never systematically monitored for these courses, but more was focused on encouraging the students to show up for tutorials. Attendance in tutorials is therefore a factor that can count into the final grade, but only if the attendance grade increases the final grade. Generally, the students were divided into tutorial groups, with each group consisting of around 20 students. It is essential to note that although the attendance grade can increase the final grade, this analysis only applies to a comparison between the final exam grade and attendance and not the final course grade. The attendance grade does not have direct input into the final exam grade.

The course assessment differs between courses, but in all the courses listed in Table 2, attendance can be a factor in the final course grade. The final course grade is calculated from various factors for learning assessment, including home assignments, group projects, midterm exams, and final exam, where the final exam can account for a maximum of 70% of the course grade.

Table 2. Summary of the courses in the dataset used in the study.

| No. | Course Name    | Year | Sem-ester | No. of students taking the final exam | Attendance weight in final grade* | Attendance grade calculation and weight                                                                                                                  |
|-----|----------------|------|-----------|---------------------------------------|-----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | Physics I      | 2019 | 1         | 188                                   | 10%                               | Attending at least 2/3 of tutorials gives a 100% attendance grade. Attending less than 2/3 of tutorials gives a 0% attendance grade*                     |
| 2   | Physics I      | 2022 | 1         | 161                                   | 10%                               |                                                                                                                                                          |
| 3   | Physics II     | 2022 | 2         | 139                                   | 10%                               |                                                                                                                                                          |
| 4   | Physics II     | 2023 | 2         | 159                                   | 10%                               |                                                                                                                                                          |
| 5   | Linear Algebra | 2018 | 2         | 204                                   | 10%                               | Attending at least 8 of 11 tutorials gives a 100% attendance grade. Attending <8 gives N/8 attendance grade, where N is the number of classes attended * |
| 6   | Linear Algebra | 2019 | 2         | 195                                   | 10%                               |                                                                                                                                                          |
| 7   | Calculus II    | 2019 | 2         | 127                                   | 10%                               |                                                                                                                                                          |
| 8   | Calculus I     | 2019 | 1         | 211                                   | 10%                               | Attending at least 7 of 10 tutorials gives a 100% attendance grade. Attending <7 gives N/7 attendance grade, where N is the number of classes attended * |
| 9   | Calculus I     | 2022 | 1         | 215                                   | 5%                                |                                                                                                                                                          |
| 10  | Linear Algebra | 2022 | 1         | 183                                   | 5%                                | Attending at least 6 of 8 tutorials gives a 100% attendance grade*                                                                                       |
| 11  | Energy         | 2022 | 1         | 161                                   | 3%                                |                                                                                                                                                          |

|  |  |  |  |  |  |                                                                   |
|--|--|--|--|--|--|-------------------------------------------------------------------|
|  |  |  |  |  |  | Attending less than 6 of 8 tutorials gives a 0% attendance grade* |
|--|--|--|--|--|--|-------------------------------------------------------------------|

\*Attendance only counts into the final grade if it increases the final grade. If the attendance grade lowered the final grade, it was omitted from the final grade, and the final exam grade weighted more in the final grade.

The following applies to the data from the courses listed in Table 2:

- All the courses had 4x45 min lectures per week and 2x45 tutorials per week during the 12-week semester.
- Attendance grade was calculated into the final grade, but only if it increased the final grade. The final exam weighed more if the attendance grade did not increase the final grade.
- Attendance was only registered for tutorial classes and not for the lectures.
- If students took both the final exam and the retake final exam, or only the retake final exam, the grade from the retake exam was used for the dataset.
- Students who had attendance registered but neither took the final exam nor the retake exam were excluded from the dataset.
- The attendance grade did not count into the final exam grade but only into the final grade.

The dataset summarized in Table 2 was analyzed in the following manner. The final exam grades for students who got 100% grade for attendance (the calculation of the attendance grade is shown in Table 2) are compared to the final exam grades of students who became attendance grades below 100%.

## RESULTS

Table 3 shows the results of the average final exam grades for the two groups; one group consists of students who achieved 100% attendance grade, the other where students achieved attendance grade below 100%.

Table 3. Results of final grades and attendance grades for the courses listed in Table 2.

| Course no. | Average final exam grade where attendance grade was 100% | Average final exam grade where attendance was <100% | No. of students with 100% attendance grade | No. of students with <100% attendance grade |
|------------|----------------------------------------------------------|-----------------------------------------------------|--------------------------------------------|---------------------------------------------|
| 1          | 70%                                                      | 58%                                                 | 41                                         | 147                                         |
| 2          | 68%                                                      | 66%                                                 | 127                                        | 34                                          |
| 3          | 72%                                                      | 64%                                                 | 39                                         | 100                                         |
| 4          | 69%                                                      | 59%                                                 | 124                                        | 35                                          |
| 5          | 67%                                                      | 49%                                                 | 134                                        | 70                                          |
| 6          | 65%                                                      | 56%                                                 | 127                                        | 68                                          |
| 7          | 68%                                                      | 60%                                                 | 97                                         | 30                                          |
| 8          | 71%                                                      | 49%                                                 | 173                                        | 38                                          |
| 9          | 63%                                                      | 46%                                                 | 160                                        | 55                                          |

|    |     |     |     |    |
|----|-----|-----|-----|----|
| 10 | 63% | 52% | 124 | 59 |
| 11 | 74% | 62% | 110 | 51 |

Figure 1 shows a graphical representation of the results for the two groups of students, one where the students got 100% attendance grade and the other group where the students got <100% attendance grade in the course.

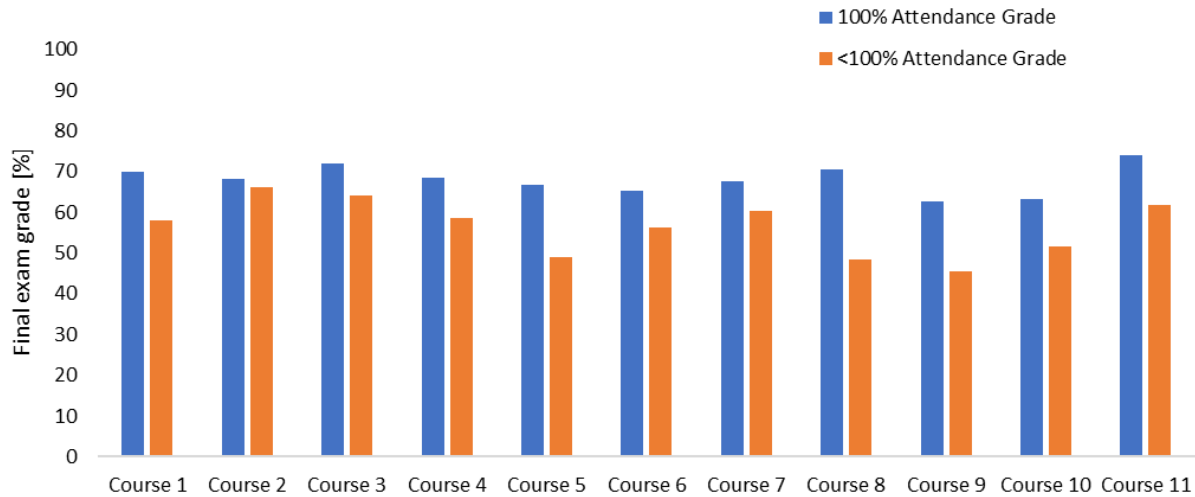


Figure 1. Results of the comparison of the final exam grades of two groups of students; one group consists of students that got 100% attendance grade, and the other group consists of students that got <100% attendance grade.

The results shown in Table 3 and Figure 1 indicate that there might be a positive relation between the final exam grade and the student's attendance in the tutorials. This is evident in all courses that were analyzed, and the difference in the average final exam grades of the two groups (one with 100% exam grade and the other with less than 100% exam grade) is between 2 and 22%.

## DISCUSSION

Data from eleven first-year engineering courses at Reykjavik University were analyzed regarding students' final exam grades and attendance. It is important to note that the attendance grade is not a part of the final exam grade, but it can weigh into the final course grade.

Figure 1 shows results from the comparison between the students who had sufficient attendance in tutorials and students who showed up less often. It is clear from these results that students who are active in attending tutorials onsite are more likely to get higher final exam grades than the other group. This is the case for all the 11 courses where the grades were analyzed.

There is a clear indication that students who show up for class do better in their final exams. This is not statistically analyzed in this paper, although the average grades of the two groups that differ in their attendance grade are compared. It would be highly interesting to collect data from more courses and perform a study showing if there is a direct relation between these two

factors: exam grade and attendance. Also, other factors that could affect the performance in the final exam, like time spent on non-academic activities, students' accessibility to resources, and students' self-directed learning abilities, could be affecting the exam grades, but these factors were not included in the study.

## CONCLUSION

In today's learning environment, online solutions can enable students to access learning material online without showing up for classes. However, the results shown in this study, as well as other studies found in literature, can encourage students to show up for classes and become more engaged and active in learning as there is a strong indication that they will perform better in their final exam if they are active in attending tutorials.

It would be interesting to analyze these results in more detail and perform a statistical analysis of the correlations between these factors, attendance, and final exam grade. It would also be interesting to extend the perspective of the student's performance to factors other than attendance in tutorials, which are also important factors and are not included in this work.

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# FACTORS THAT MAY IMPACT CURRICULUM DESIGN IN HIGHER EDUCATION IN A VUCA WORLD

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## ABSTRACT

Higher Educational Institutions (HEIs) have been characterized by volatility, uncertainty, complexity, and ambiguity (VUCA), with the Covid-19 pandemic being a recent example, which significantly affected higher education worldwide. The aim of this research was to better understand which components of curricula are sensitive to potential VUCA-like events, and which VUCA events one may foresee that may impact study programs and teaching. A survey was developed to gather data, and thirty-seven faculty members with experience in curriculum design from six countries participated in the survey which was carried out in 2023. To start with, we outlined the different components of a curriculum which then formed the basis for evaluating their perceived sensitivity to VUCA-like events. Based on the survey we then analyzed and summarized the factors that may potentially impact the curriculum. The components of a curriculum that are most sensitive to VUCA-like events are the ones directly related to the actual teaching and learning processes. In addition, the study findings indicated that when considering potential VUCA-like events, Artificial Intelligence (AI) was expected most likely to significantly affect educational programs, followed by events such as disinformation online, cyberattacks, disrupted online communication, as well as climate change and natural disasters. The increasing VUCA characteristics of the world are expected to affect the curriculum in general and in particular the actual teaching and learning. Therefore, HEI leaders and curriculum designers need to ensure that the HEI system is responsive to the VUCA-like events and that the system becomes resilient.

## KEYWORDS

Curriculum design, curriculum sensitivity, VUCA events, CDIO Standards: 1-12.

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## **INTRODUCTION**

Most countries provide educational guidance on what to teach and the educational process at each school level; this guidance is referred to as the curriculum or curriculum standards. The curriculum is important to identify the focus of the content, describing the degree of learning appropriate for the preparation of students for the future, and to ensure the introduction of the content in relation to the goal of the education. The complexity of the modern world requires a curriculum that transcends disciplinary boundaries, and which is resilient (Ciolacu et al., 2023; Ramsaroop, 2023). Interconnected global challenges such as climate change, economic inequality, and technological innovation demand an interdisciplinary approach to education. Curriculum designers must emphasize the integration of diverse perspectives, fostering a holistic understanding of complex issues and preparing students to engage with multifaceted problems (Ciolacu et al., 2023).

In the ever-evolving landscape of higher education, educators and curriculum designers find themselves grappling with the challenges posed by the volatile, uncertain, complex and ambiguous (VUCA) nature of today's world (Pannipa et al., 2023; Rouvrais et al., 2023), which has been characterized by pandemics, wars, and erratic weather (Rockley, 2022), and an uncertain future which may bring about further surprises. Multiple disruptions in Higher Educational Institutions (HEIs) over the years have resulted in curriculum leaders having to consider the relevance and impact of the programs that are offered. The Covid-19 pandemic was particularly disruptive for higher education as a whole (Ramsaroop, 2023), and resulted in many HEIs being pushed rapidly into much-needed technological advancement (Ciolacu et al., 2023). HEIs have to be proactive and agile to be able to respond to the multiple disruptions in the external and internal environments.

In engineering education, the principles of VUCA offer a strategic lens through which to comprehend and address the multifaceted landscape that engineers must navigate (Kamp, 2023). Furthermore, program leaders have to design and operationalize their curricula in a context of unknown changes (Ciolacu et al., 2023). Designing a curriculum involves defining and describing its components and structure (van den Akker, 2004). When ascertaining the factors that may impact the curriculum, in particular from potential VUCA-like scenarios, one way to do so is to look at the effect they may have on these components.

The authors of the paper are part of a project called DEPART and are from the fields of STEM and management education. The project is an international cooperation partnership, including France, Germany, Iceland, Indonesia, Lithuania, and South Africa. The primary goal is to allow partner's organizations to develop new practices and methods as well as sharing and confronting ideas in curriculum design, with a focus on Designing higher Education Curricula for Agility, Resilience and Transformation. Here in this paper, we focus on one aspect of the project by examining curriculum design within the context of a VUCA world.

In this paper, we present results from a survey that was carried out to better understand which components of curricula are sensitive to potential VUCA-like events, and also VUCA events one may foresee that could impact study programs and teaching in higher education. The respondents who completed the survey are mostly from STEM and management education.

## **LITERATURE REVIEW**

Policy documents from OECD and UNESCO emphasize the need to support today's students to develop skills and attitudes to survive and succeed in a VUCA world (Hadar et al., 2020). Looking through the VUCA lens provides an opportunity to understand the dynamic forces at

play in the contemporary educational environment (Ramsaroop, 2023; Niemczyk, 2023). As industries undergo rapid technological advancements, globalization reshapes collaboration, and societal needs evolve. It becomes imperative for higher education curriculum designers to adopt an adaptive, forward-thinking approach.

In the abbreviation VUCA, volatility refers to the frequent, rapid, and unpredictable changes that characterize today's world (Bennett & Lemoine, 2014). It is critical to understand the opportunities and threats which are present in the situation, and to embrace agility to deal with the volatility. Uncertainty acknowledges the lack of predictability and the prevalence of unknowns, and essentially relates to the lack of adequate information (Bennett & Lemoine, 2014). Complexity recognizes the intricate interconnections that shape educational contexts, with a complex situation being defined by many interconnected parts (Bennett & Lemoine, 2014). Ambiguity acknowledges the haziness of situations where cause-and-effect relationships are unclear, and where there is little precedent to enable predictions to be made (Bennett & Lemoine, 2014). In the realm of curriculum design, embracing VUCA is not merely a response to these VUCA challenges, but an opportunity to foster resilience, innovation, and lifelong learning skills among students.

Prideaux (2003) argues that “The curriculum represents the expression of educational ideas in practice. The word curriculum has its roots in the Latin word for track or race course. From there it came to mean course of study or syllabus. Today the definition is much wider and includes all the planned learning experiences of a school or educational institution”. Curriculum furthermore refers to the formal requirements for the degree or syllabus, and is usually composed of contents and topics relating to lectures, reading lists, and content knowledge (Annala & Mäkinen, 2011). The more holistic definition of the higher education curriculum provided refers to “an intentional and dynamic process, which reveals the values and principles in relation to learning, knowledge and disciplines, and cultural and political purposes of HE” (Annala & Mäkinen, 2011, p. 4).

## **RESEARCH METHODOLOGY**

To achieve the aim of this research, as stated in the Introduction section, we developed an online survey. As is evident from the above review of the literature, a curriculum may have varied meanings and different structures, so we started out by analyzing the structure of actual curricula used in STEM and management education for the purpose of this research. Firstly, the curriculum is designed within the overarching external constraints, which may include national policies, stakeholders, and accreditation bodies. Secondly, curriculum is often presented as a set of components (e.g. van den Akker, 2004; Jonnaert et al., 2021).

In this research, we used actual examples of curricula presented by all six partners in the DECART project and based on an analysis of them, we developed a harmonized curriculum model consisting of nine components. This model is in general agreement with conventional curriculum models (e.g. van den Akker, 2004), with some components being basically the same, but there are additional components which include stating explicitly entry requirements (#2), on interpersonal skills (#6), language (#8) and ethno- and sociographic aspects (#9). As the model is based on actual curriculum, it may reflect more the current situation concerning programs in higher education. The components of this harmonized curriculum model, and which are used as the basis in the main survey, are:



1. Main goals and learning outcomes of the program, including its objectives.
2. Entry requirements for students entering the program.
3. Structure and content of the program, including the sequence of courses, content and learning activities and length of program.
4. Teaching methods and learning in the program, including the role of the teacher and teaching material.
5. Location of teaching and learning in the program, including being on campus or not, or a hybrid combination.
6. Teaching and learning of interpersonal skills in the program, including communication and teamwork.
7. Assessment methods in the program.
8. Language of instruction in the program.
9. Ethno- and sociographic aspects of the program, including diversity and equity.

A survey was conducted; a preliminary version of the survey which was developed initially focused only on VUCA events and then it was later finalized and constitutes the main survey. The preliminary survey was conducted in June of 2023 with a small subset of the respondents that participated in the main survey which was conducted in October and November of 2023. The main survey was sent to several faculty members at six different institutions of higher education, all of which are involved in the DECART project. At each institution, one person was responsible for sending the survey to faculty members that were either directly involved in curriculum design or responsible for running educational programs. These members received a link to the survey which was conducted online.

In the survey, the faculty were asked to consider which components of the harmonized curriculum model might be affected by some VUCA-like events, and also which potential VUCA scenarios they foresee might happen in the future and affect current educational programs. The purpose was to evaluate the sensitivity of different components of the curriculum to unexpected VUCA-like scenarios. The survey was composed of four parts. The first part presented three background questions, i.e. on involvement or experience with STEM, management or other education, on expertise in curriculum design, and the country where one is based. This was followed by nine questions directly related to the different components of the curriculum model as outlined above. The third part presented six general questions on specific potential VUCA-like scenarios. The fourth part was to allow respondents to make open remarks on potential VUCA-like scenarios that may impact the program, as well as on the survey in general. As VUCA is not a common term and perhaps not understood in the same way by all, in the survey we used the phrase "unexpected and forceful event". The scale used for the responses were based on the five-point Likert scale, with "Totally disagree" and "Totally agree" at the ends of the scale.

When asked to rate their expertise of program curriculum design, 35 out of 37 respondents indicated expertise, and only two out of the 37 indicated that they had little or no expertise. Table 1 shows the total number of respondents.

Table 1. Number of respondents, field of education and countries.

|              | Involved with STEM education | Involved with Management education | Other | Total     |
|--------------|------------------------------|------------------------------------|-------|-----------|
| France       | 4                            | 5                                  | 0     | 9         |
| Germany      | 4                            | 0                                  | 0     | 4         |
| Iceland      | 8                            | 0                                  | 0     | 8         |
| Indonesia    | 2                            | 1                                  | 1     | 4         |
| Lithuania    | 4                            | 1                                  | 1     | 6         |
| South Africa | 0                            | 6                                  | 0     | 6         |
| Total:       | 22                           | 13                                 | 2     | <b>37</b> |

There are several ways to analyze the data based on the responses on the Likert-scale, including statistical methods or simple fractions. Here we want to focus on the number of respondents that agree with the given statement compared to the respondents that disagree. Therefore, to distinguish these positive agreements, we used the number of responses in categories “Strongly agree” and the one next to it (“Agree”) and compared it to the number of responses in “Strongly disagree” and the category next to it (“Disagree”) by using a simple ratio of the two. This bias ratio is labeled  $R$  in Tables 2 and 3. In the analysis of the data, we consider a response convincingly positive if the bias ratio  $R$  is two or higher and the mode is on the positive side, i.e. either “Agree” or “Strongly agree”.

## RESULTS AND DISCUSSION

### *Sensitivity of components of the curriculum*

In the survey, nine statements were focused on the sensitivity of each of the different curriculum components to VUCA-like scenarios. The components were the ones of the adapted curriculum model as presented in the Introduction section. All the statements had the same structure, i.e. “I am concerned that the *main learning outcomes* of the program, including its goal and objectives, will change significantly in the near future due to unexpected and impactful events”, and so on. The words in italics in exemplary statements above were replaced by the ones listed in Table 2. Counts of the responses are presented in Table 2.

Table 2. Sensitivity of different curriculum components. Entries represent the number of responses for each category.

| <i>Component</i>                     | Likert scale category |   |           |           |                | $R$        |
|--------------------------------------|-----------------------|---|-----------|-----------|----------------|------------|
|                                      | Strongly disagree     |   |           |           | Strongly agree |            |
| 1. main learning outcomes            | 4                     | 7 | <b>11</b> | 10        | 5              | 1,4        |
| 2. entry requirements                | 5                     | 8 | <b>11</b> | 8         | 5              | 1,0        |
| 3. structure of the program          | 3                     | 8 | 8         | <b>11</b> | 6              | 1,5        |
| 4. teaching methods                  | 3                     | 5 | 7         | <b>15</b> | 7              | <b>2,8</b> |
| 5. location of teaching and learning | 1                     | 9 | 7         | <b>16</b> | 4              | <b>2,0</b> |

|                                     |           |           |   |           |   |            |
|-------------------------------------|-----------|-----------|---|-----------|---|------------|
| 6. teaching of interpersonal skills | 2         | 7         | 7 | <b>13</b> | 7 | <b>2,2</b> |
| 7. assessment methods               | 3         | 6         | 8 | <b>13</b> | 7 | <b>2,2</b> |
| 8. language of instruction          | <b>10</b> | 9         | 7 | 8         | 3 | 0,6        |
| 9. ethno- and sociographic aspects  | 2         | <b>13</b> | 8 | 10        | 4 | 0,9        |

Four components have both distinctly higher  $R$  than the rest of the statements and modes on the agree-side, satisfying our criteria of being convincing. Therefore, there are four components of the curriculum that the respondents were concerned about that may change, and may therefore be more sensitive to unexpected and impactful events. These four components are Teaching methods ( $R=2,8$ ), Location of teaching and learning ( $R=2,0$ ), Teaching of interpersonal skills ( $R=2,2$ ) and Assessment methods ( $R=2,2$ ).

The sensitivity of Teaching of interpersonal skills (#6) may be due to shifts in the world of work, coping with studies, and perhaps this is a skill that has not received enough attention over the years. One may argue that the other three (#4, 5 and 7) of these components are considered more sensitive because of the impact of the Covid-19 pandemic, like online teaching and learning, more options in teaching methods and assessments, and the uncertain effects that AI may have on higher education. These changes will certainly affect faculty, as they have no option but to adapt, but they may not know how exactly to do so.

### **Potential VUCA events**

The statements on six specific potential VUCA events in the main survey were based on the most frequently mentioned events in the preliminary survey. In the main survey, all six statements had the same structure, i.e. "I am concerned that *AI (Artificial Intelligence)* will significantly affect the program.", and similar for the other five events (the words in italic were replaced in each statement by the ones in Table 3). The results are shown in Table 3.

Table 3. Number of responses regarding suggested VUCA like events.

| <i>Event</i>                 | Likert scale category |           |           |           |                | $R$        |
|------------------------------|-----------------------|-----------|-----------|-----------|----------------|------------|
|                              | Strongly disagree     |           |           |           | Strongly agree |            |
| AI (Artificial Intelligence) | 6                     | 7         | 3         | <b>13</b> | 8              | <b>1,6</b> |
| global warming               | 4                     | <b>11</b> | 7         | <b>11</b> | 4              | 1,0        |
| international conflict       | 7                     | 5         | 8         | <b>13</b> | 3              | 1,3        |
| local unrest or conflict     | 8                     | 9         | <b>11</b> | 7         | 2              | 0,5        |
| local access to electricity  | <b>12</b>             | 11        | 3         | 8         | 3              | 0,5        |
| too few students             | 6                     | 8         | <b>12</b> | 6         | 5              | 0,8        |

Of the suggested events, only AI stands out as a major area of concern, when considering both the mode of responses and the bias ratio  $R$ . Local access to electricity appeared to be of least concern (on the other hand load-shedding is rather common in South Africa). The bimodal response for Global warming is intriguing and indicates that concern for it may be site dependent, and the same applies for local access to electricity. Although we use the term event, some of them may be prolonged over some time and still have the VUCA characteristics.

AI may be so prevalent in the survey because it is so topical today in daily discussions, but it is also clear that AI poses both a threat as well as creates opportunities for higher education, both in terms of teaching and learning, and in the assessment of students. How HEIs deal with AI and take advantage of it, is outside the scope of the survey and this research.

**Qualitative results on not foreseen and potential VUCA events**

In both the preliminary and the main survey, some questions were directly related to potential VUCA events. In the preliminary survey, we asked about VUCA events in three different timeframes, i.e. events that one was not able to foresee, and then events that one may anticipate in the next three and in the next 50 years. As the events indicated for these two latter timeframes were similar and the results from the main survey were comparable, the listings from both were combined. In the main survey we asked: *“Outline the events or items that you are concerned about that may affect the program or your teaching due to an unexpected and drastic event. Up to five (5) items can be mentioned”*. This was implemented by filling in the underlined space: *“I am concerned that \_\_\_\_\_ will significantly affect the program or my teaching.”* These potential events are summarized in Table 4, and are often rephrased for the sake of brevity.

Table 4. VUCA events that have already occurred and potential VUCA events in the future.

|                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>VUCA events that you have encountered or have already taken place, that you were not able to foresee:</p>                                                                                                                                                                                                                   | <p>Potential VUCA events in the near future that may significantly affect the program or my teaching (the first items are in order of how often they were mentioned):</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <ul style="list-style-type: none"> <li>• Covid-19</li> <li>• software crash</li> <li>• no electricity</li> <li>• no classroom</li> <li>• sudden online teaching</li> <li>• student strikes</li> <li>• cancellation of classes due to low student enrolment</li> <li>• availability of faculty for specific courses.</li> </ul> | <ul style="list-style-type: none"> <li>• AI</li> <li>• disinformation online</li> <li>• cyberattack, disrupted online communication</li> <li>• climate change and sustainability megatrends</li> <li>• natural disasters</li> <li>• political instability and war</li> <li>• student recruitment dropping</li> <li>• not well enough prepared students</li> <li>• generation gap and different approaches</li> <li>• cultural mixing and adaption, including xenophobia</li> <li>• increasing inequality</li> <li>• mental health</li> <li>• financial cost of program</li> <li>• slow response of HEI to external change</li> <li>• not enough qualified teachers</li> <li>• motivation of teachers</li> <li>• governmental funding</li> <li>• governmental requirements.</li> </ul> |

It is evident that even though a particular VUCA event may be suggested (second column in Table 4), its potential effect on specific curriculum components and on operating an educational program, may not always be stated nor is its effect clear. This may reflect the fact that the effects on educational programs are ambiguous and that several different VUCA-like events and scenarios may have similar or the same effect on operating an educational program (e.g. Berthoud et al., 2021).

## **End-of-survey comments**

At the end of the survey, space was provided for optional comments from the respondents. They were able to be classified into two groups. One was on the exact meaning of “I am concerned about ...” as used in the statements on the curriculum components. The other group of comments reflected the different understanding of what constitutes a VUCA-like event among the persons responding to the survey. This was reflected in quotes such as:

*“I do not really understand the “I am concerned about” language.”*

*“... I am not concerned about most of the events in question, indeed, I am looking forward to disruptive events leading to change of, e.g. assessment methods or the usage of AI in teaching.”*

*“... I think mainly my health and motivation may affect the program and my teaching.”*

*“VUCA factors are not just push or pull factors like fire, flood, or even war.... simply listing the factors that will affect the curriculum is not within the scope of VUCA.”*

*“... very good survey, push thinking and rethinking”*

## **CONCLUSION**

The aim of the study was to determine which components of a curricula are sensitive to potential VUCA-like events, and which VUCA events faculty may foresee that could impact programs and teaching in the near future. As curricula may have different structures, meaning and purpose at different educational institutions, we adapted a particular curriculum model based on actual examples from six different institutions as outlined in the Introduction section. This model has nine components, which formed the basis for evaluating the different components with respect to different VUCA-like events. Thirty-seven faculty members from six countries related to the DECART project responded to the survey, most of whom had at least some expertise in curriculum design.

Results from the survey showed that four of the nine components of the curriculum may be considered sensitive to VUCA-like events according to the perception of the respondents, i.e. teaching methods, location of teaching and learning, assessment methods and teaching of interpersonal skills. The first three are in essence how one actually conducts the teaching and facilitates the learning, and may to some degree reflect the impact that Covid-19 had on higher education and the ambivalent anticipation of AI and its effect on education. The focus on interpersonal skills may reflect the increasing need for such skills in the workplace, as well as during the learning process and perhaps it is an ongoing endeavor in higher education. Interpersonal skills are mentioned in 6 out of the 12 standards of CDIO ([www.cdio.org](http://www.cdio.org)), so the relevance is not new to the CDIO community. Therefore, one may expect that these four components are indeed on the list of topics currently under review at many HEIs or may be added to such a list. When considering potential VUCA-like events that may affect educational programs, AI was of most concern, in an ambivalent manner, followed by events like disinformation online, cyberattack, disrupted online communication, and then climate change and natural disasters. It is important to realize that VUCA-like events may indeed significantly affect curricula, and may also lead to positive developments and changes. In addition, the potential VUCA events being considered may inherently be biased towards topical issues.

Considering the perceptions that emerged from the survey, the factors that need to further examined, especially when designing curriculum, is the way in which teaching is actually conducted and learning facilitated, and specifically how AI may impact the curriculum. Due to

the few respondents, given the nature of the study, one should be careful in generalizing the results, which essentially represents exploratory indications and perceptions of the respondents at the time that the study was conducted.

The VUCA events and scenarios which were identified, are presently being further explored in the DECART project and refined through cooperative workshops with faculty and other stakeholders. Such events will allow for the development of good to best practices regarding curriculum resilience and adaptation.

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# INVESTIGATION OF STUDENT PERSPECTIVES ON CURRICULUM NEEDS FOR AUTONOMOUS SHIPPING

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## ABSTRACT

Digitalization and automation are reshaping the maritime industry, particularly through advancements in designing Maritime Autonomous Surface Ships (MASS) and the expected proliferation of autonomous shipping. These innovations are altering traditional roles in ship design, operations, and the maritime sector in general. The influx of cybersecurity, automation, and IT experts into the maritime sphere is necessary for MASS integration in logistic chains. This paper examines students' perspectives on autonomous shipping, future job markets, and educational needs related to MASS. A survey of 159 students from Finnish universities studying in the fields of IT, maritime studies, engineering, naval architecture and business and law revealed significant interest in MASS-related education, driven by its anticipated impact on their careers. The study areas of interest include automation, computer engineering, general IT knowledge, Artificial Intelligence, and cybersecurity. The findings highlight the need for interdisciplinary curricula in MASS-related education, integrating technology, safety, legal, and business aspects of MASS.

## KEYWORDS

Autonomous shipping, MASS, job market, profession.  
CDIO Standards: 2, 3.





## INTRODUCTION

Digitalization and automation are reshaping the maritime industry (Tsvetkova, Gustafsson, and Wikström, 2021). Particularly, the wide adoption of Maritime Autonomous Surface Ships (MASS) in the maritime sector is expected to affect several sectors such as logistics and shipbuilding, creating opportunities for new technological and business model innovations (Munim, 2019), while also changing the labour market. The role of the crew will, if not completely re- moved, see drastic changes in terms of tasks, responsibilities, and necessary skills (Tsvetkova, Hellström, and Ringbom, 2021). Remote operations of MASS, which are considered more likely than full autonomy at least in the near future, would require the understanding of the technology behind autonomous operations to ensure safe and secure operations, thus highlighting the importance of the knowledge of cybersecurity, Artificial Intelligence (AI) and automation. Ship- building and ship equipment manufacturing will see opportunities for further innovation, which will require professionals skilled in IT, automation, and cybersecurity, on the one hand, and in naval architecture and maritime engineering, on the other hand (Bolbot et al., 2022). Simultaneously, autonomous shipping will serve as a practical setting where IT engineers can apply their skills.

Engineering education needs to reflect these changes and prepare specialists who have sufficient knowledge and skills to design, build and operate MASS. Besides the cross-disciplinary engineering knowledge, the understanding of technical, legal and business aspects of au- tonomous shipping as a whole is relevant for these professionals. While several studies made comprehensive overviews of future skills necessary in seafarers' jobs, professionals involved in shipbuilding and maritime logistics (Bolbot et al., 2022), it is necessary to acknowledge that the labour market will evolve under many influencing factors, including the attitudes towards MASS and the perceived attractiveness of the jobs related to it. To address this research gap, this study aims to uncover the interest of current students in MASS-related education, as well as their perceptions of how the future labour markets will change due to the adoption of MASS and how this affects their professions. The study is based on a survey of students in seven higher educational institutions in Finland which provide MASS-related education. By explicating the changes students expect in their future jobs and corresponding them to the most interesting aspects of MASS-related education, we identify the commonalities and differences in the expectations towards such education among students in several relevant fields, such as maritime operations, maritime engineering and naval architecture, IT, and other engineering students.

## LITERATURE OVERVIEW

The analysis of MASS's impact on the general maritime industry has attracted interest from multiple researchers. Examples constitute the identification of skills that will be required in the general maritime industry (Bolbot et al., 2022; Cicek et al., 2019). Other researchers have undertaken the tedious exercise of determining the new skills for navigators and remote control operators (Bachari-Lafteh and Harati-Mokhtari, 2021; Baum-Talmor and Kitada, 2022; Emad and Ghosh, 2023; Saha, 2023; Shahbakhsh et al., 2022; Sharma and Kim, 2022). The impact of MASS on gender equality was investigated by Kim et al. (2019). Several studies (Akbar et al., 2021; Kooij and Hekkenberg, 2021; Ziajka-Poznańska and Montewka, 2021) conducted the techno-economical analysis of MASS operations. The impact of MASS on safety has been

investigated, too (Bačkalov et al., 2023; de Vos et al., 2021; Wróbel et al., 2017). The general impact of MASS on logistics has been considered in studies by Tsvetkova and Hellström (2021) and Tsvetkova et al. (2022), whilst the general influence of MASS on the economy has been analysed by Bolbot et al. (2020), and Jo and D'agostini (2020).

However, understanding the perspectives of the general public is also important for drawing prudent public policies in connection to MASS (Goerlandt, 2020; Van Hooydonk, 2014). Several studies have investigated the public attitude towards MASS. One of the first stakeholder perspective analyses on MASS was conducted in the Munin project (Munin, 2023), where the flag states and external stakeholders, generally endorsed MASS adoption. The investigation of general public perception towards MASS in Halifax, Nova Scotia, Canada by Goerlandt and Pulsifer (2022) demonstrated that the general public might have safety concerns in connection to remotely controlled MASS and that men generally see MASS more favourably than women. Multiple stakeholders' perspectives towards MASS were investigated in a study (Theotokatos et al., 2023), where a generally positive attitude towards MASS was confirmed, but a seeming resistance from seafarers towards MASS was also identified. This finding was partially confirmed in Chan et al. (2023), where the seafarers expressed their concerns in connection to jobs security.

Yet, the students' perspectives towards MASS were largely omitted in this and other studies. This constitutes an important research gap. Furthermore, the perspectives of students in connection to MASS-related courses have not been reported in previous literature to the best of the authors' knowledge. This gap is addressed in this study.

## **METHODOLOGY**

In this study, we conducted research on student interest in MASS-related education to understand how this group perceives the impact of MASS and affects their interest in particular topics. We were driven by the question of whether students within and beyond traditional maritime-related education find MASS-related education relevant, and how the study interests differ across students with different educational backgrounds. The study began by aggregating contact information from teachers who teach MASS-related courses at the partner institutions of the Finnish autonomous maritime university network AutoMare (Bolbot et al., 2022) and asking them to distribute the questionnaire to their students. To ensure the validity of the questionnaire, it was designed in collaboration with teachers from partner institutions, including a broad range of disciplines within MASS-related education. Thus, the list of options for which aspects of MASS-related education was built based both on reviewed literature and the experience of these teachers. The options to provide own open answers were added so that respondents would have the possibility to add new items and would not be constrained by the proposed categories.

The survey was conducted in April 2023 and was filled by 159 students from several Finnish higher education institutions. The survey response rate was not calculated given that it was an open invitation to multiple email lists to voluntarily respond. Students from Novia University of Applied Sciences, South-Eastern University of Applied Sciences, Satakunta University of Applied Sciences, Turku University of Applied Sciences, University of Turku, Aalto University, and Åbo Akademi University were among the respondents.

The survey included questions on students' demographics, education, and interest in studying in courses related to autonomous shipping. Initial inquiries covered age, university, degree, and field of study. Following this, participants were asked about their motivations for studying autonomous shipping and the specific aspects they find of interest to study (based on Bolbot et al., 2022). The survey also explores potential barriers to related course participation and identifies preferences for elective courses and study methods. These questions, however, are not included in the scope of this study. The final questions were open-ended and touched on opinions on the impact of MASS on job markets and the students' views on the role of the person who should be in charge of an unmanned ship. The questions used in the survey are listed in the Appendix. The answers to the questions marked with (\*) have been used in the analysis presented in this paper. The answers to open-ended questions were analyzed using content analysis and the discussed topics were thematically grouped into several key topics to understand students' perspective on the job market changes and the descriptions of their future jobs. This served as a context for analyzing quantitatively their answers related to the aspects, they are interested in studying and their general interest in MASS-related education.

## RESULTS

### Sample characteristics

A total of 159 responses were collected during the survey. The respondents' educational degrees are distributed as follows. A prominent respondent segment is studying for bachelor's degrees, constituting a majority share of 60.4%. Individuals studying for master's degrees from universities stand at 30.8%. The share of respondents aiming for vocational degrees or secondary school qualifications is at 6.3%. The remaining percentages are allocated to a category encompassing other degrees, including doctoral degrees, licentiate degrees, master's degrees from universities of applied sciences, as well as qualifications equivalent to comprehensive school education (see Figure 1).

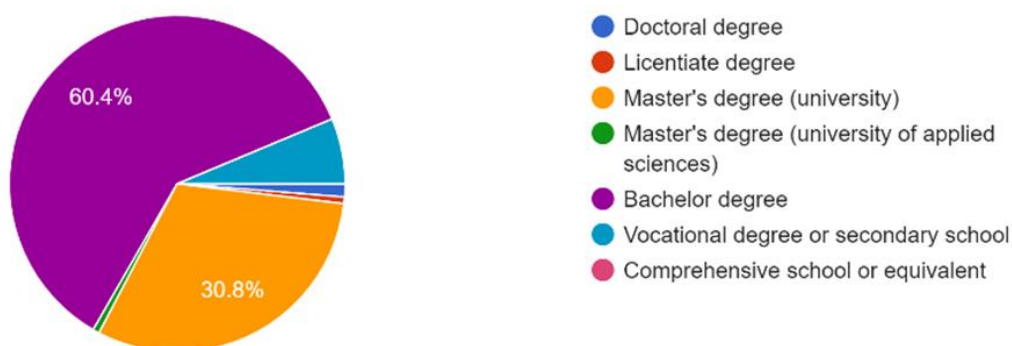


Figure 1. Respondents' degrees

The respondents represented a diverse array of study fields, which was beneficial for understanding the cross-disciplinary aspects of MASS-related education. Information Technology (IT) represented 34% of the survey respondents. Students in maritime engineering and naval architecture, as well as students in other engineering (such as e.g. process and chemical engineering) constituted 18% of respondents each. 15% of students

were studying for a degree in maritime operations and navigation. Finally, 12% of students were in natural sciences (such as marine biology), and 3% were studying in the fields of business, law, social and other sciences (see Figure 2).

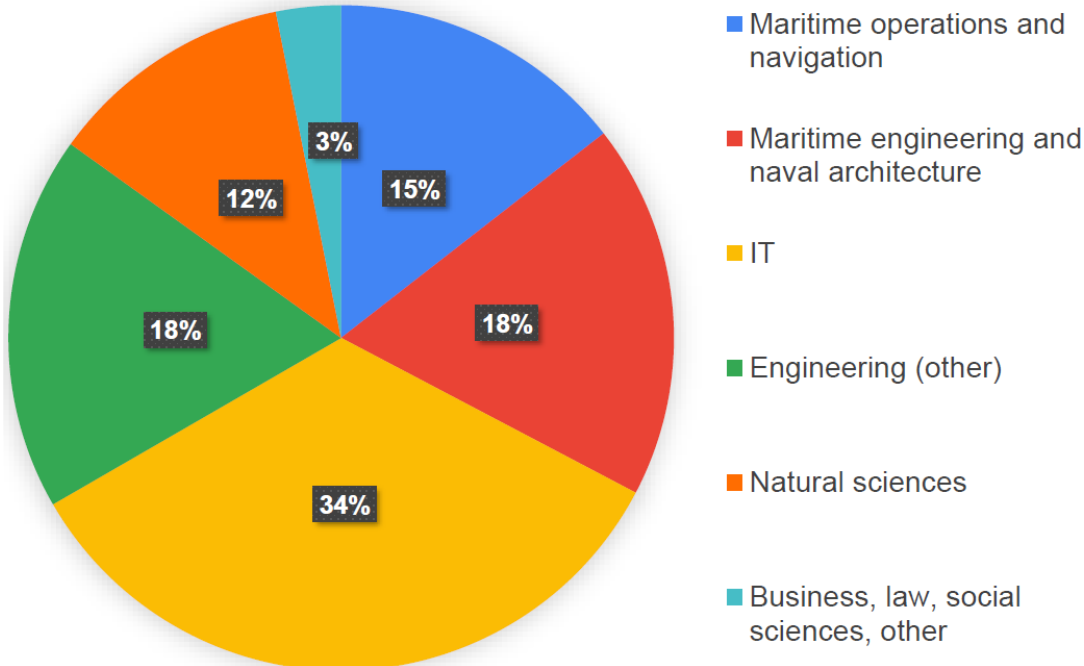


Figure 2. Main fields of study of the respondents (N = 159)

**Students’ perspective on the changes in the job market in response to autonomous shipping**

During this study, respondents were asked to share their visions and opinions regarding the future of autonomous shipping and its impact on existing and future jobs. A recurring topic in terms of new job possibilities that may emerge as a result of the broad deployment of autonomous shipping is the significant need for IT specialists and automation engineers. The development of MASS systems, requiring expertise in software development, AI, machine learning, and autonomous system design, stands out as a necessary condition for successful autonomous shipping.

Beyond technology, the importance of cybersecurity in safeguarding these advanced vessels was emphasized. Legal and regulatory compliance is another area that was often mentioned. Professionals experienced in maritime regulations will be crucial to ensuring adherence to international and national laws and navigating the particulars of the changing regulatory landscape. The management and oversight aspect of autonomous shipping is anticipated to create new jobs as well. Supervising transactions, shipping processes, and managing autonomous ship operations will necessitate professionals to ensure efficient functioning. Furthermore, the environmental impact and sustainability of autonomous shipping were highlighted by several respondents. As the industry shifts, professionals with the expertise to evaluate the environmental footprint of these vessels and ensure sustainable practices are expected to become increasingly valuable. Finally, it was mentioned that rather than creating new jobs, the wider diffusion of autonomous shipping would change the job descriptions of seafarers

and that the crew size would gradually reduce.

According to students, concerning the jobs that will cease to exist, the advent of autonomous shipping is expected to lead to higher automation or reduction of several traditional job roles within the maritime industry. Based on the respondents' comments (78 responses), crew members, such as deckhands, engineers, and navigators, may face diminished roles or potential elimination due to the autonomous operation of ships. Pilots<sup>1</sup> and harbour masters<sup>2</sup> might see reduced demand as autonomous vessels navigate ports independently. Additionally, stevedores involved in loading and unloading cargo could experience a decrease in employment opportunities, as automated cranes take over these tasks. Furthermore, students anticipate that marine surveyors may encounter a change in their roles as advanced sensors and monitoring systems reduce the need for extensive manual inspections. The occupation of captains and deck crew members could witness shifts in responsibilities or reduced demand as autonomous ships take over navigation tasks.

As can be observed from the opinions regarding the jobs that will change or become obsolete, the roles of the crew members are expected to be affected the most. The changes to the role of the Master of a ship<sup>3</sup> are especially challenging to foresee, given the unclear responsibility if accidents happen involving a MASS. Thus, the respondents were asked who the Master (or captain) of an unmanned ship should be, i.e. someone who holds the highest authority and responsibility for the safe and efficient operation of the ship. The most common opinion (around 51% of the respondents) is that a person responsible for the remote operation of the ship (e.g. a shipping company executive) should bear this responsibility. Almost as many respondents considered the remote operator to be a suitable person who can be considered the Master of a MASS. Around 21% of respondents suggested that any qualified person appointed by the shipowner can serve this function, while 7,5% of respondents believed that no Master is required for an unmanned ship onboard.

The question of who should hold the position of master on an unmanned ship has generated diverse viewpoints. While some respondents foresee a gradual shift towards increased autonomy in maritime operations, particularly for short-voyage cargo vessels, others stress the importance of maintaining a human presence in critical roles. It is suggested that this person should possess both expertise in manual ship navigation and training in remote control technology, ensuring their ability to intervene in unforeseen circumstances. This approach is seen as a balance between technology-driven automation and the need for human intervention. A perspective is also offered that unmanned ships may not become a reality within the respondents' lifetimes. Instead, they express interest in systems that enhance autonomy while still involving human oversight. Some respondents believe that the shipping company should assume ultimate responsibility, with remote operators functioning as pilots or Vessel Traffic Services (VTS). They argue against attributing sole responsibility to an individual who lacks full control over the ship's systems.

<sup>1</sup>A pilot is a local advisor to the ship master who provides navigational assistance to vessels sailing along the fairways and increasingly ensures the safe manoeuvring of ships to quays in destination ports.

<sup>2</sup>A harbour master is the official in charge of a harbour

<sup>3</sup>Master of a ship is the term that is given to the captain of a ship or the chief commanding officer of a ship.

As discussed in the following section, the changing roles of technology and crew influence the perceived educational needs of the students, especially those within the maritime domain.

### ***Interest in MASS-related education***

To understand the interest in MASS-related education among students, they were asked whether they were interested in studying courses in autonomous shipping. The term 'autonomous shipping' was used in the survey to ensure that students who are not familiar with a rather specific term MASS can understand the question, and that subjects beyond MASS design, construction and operation can also be included. The majority of all respondents (62,3%) claim they are interested in the subject, while around a quarter of students neither agree nor disagree with the statement that they are interested. Only around 11% of students say they are not interested in studying courses related to autonomous shipping. Therefore, strong interest in MASS-related topics from students was concluded.

To better understand the students' interest in MASS-related education, we analysed how the responses differed based on the student's background. As can be seen from Figure 3, there is a pronounced interest in MASS-related education among students in the maritime professions, including those related to shipbuilding and ship operations. IT students and students in engineering (other than those directly connected to maritime engineering) also appear to be interested in such education, while students in natural sciences appear to have a lower interest in the subject. The interest in MASS-related education is not very pronounced among students in business, law, and social sciences, too.

Further, students explained the reason for their interest in MASS-related education, if present, citing most commonly the general interest in new technologies and ship designs and the belief that there will be more MASS operating in the future. Around a third of the respondents believe that knowledge of autonomous shipping will be needed in their future work. Only around 20% of students believe that autonomous shipping will radically change the field they are studying or working within.

Students mentioned other reasons for their interest in addition to those listed above. Some students are intrigued by the practical applications and technical aspects of autonomous systems, seeing the potential for cross-field utilization and the widening of their knowledge. Others express interest in specific areas, such as robotics, AI, and information security, with a desire to explore autonomous systems, including ships, as part of their educational curriculum. There is also a distinct interest in understanding the environmental impact and the potential to develop environmentally friendly autonomous vessels. Additionally, some students share a broader interest in AI and automation, often without a clear connection to shipping. A few students mentioned that they are already engaged in the autonomous vessel industry through their current work or thesis focus. Several students have reservations about the practicality and speed of widespread autonomous shipping adoption, emphasizing the continued need for human involvement and careful consideration of the risks involved. As one respondent commented, "There are huge information security concerns in this type of ship".

Different aspects of the subject raise the interest among the respondents. Automation, computer engineering and basic knowledge of IT and operational technology are the most com-

monly mentioned topics that students would like to study in regards to autonomous shipping (see Figure 4).

Other commonly mentioned topics include those related to IT, such as artificial intelligence and data analytics, and safety and security aspects of MASS. Although topics related to ship design and ship systems automation are mentioned less, this can be explained by the fact that these are the subjects relevant mostly to professionals in the shipbuilding sector. Additionally to the aspects listed in Figure 4, topics like the impact of MASS on wildlife and marine environments, legal considerations tied to personal freedom, and electricity-related aspects were mentioned as areas of interest.

We further analyzed the most commonly mentioned aspects of autonomous shipping that different student groups are interested in studying. As can be seen from Figure 5, the interests differ depending on the current field of study, although some aspects appear to be universally important for students. This includes automation and basic knowledge of IT and operational technology. Safety aspects related to autonomous shipping and cybersecurity are highly prioritized by students from different fields. It can be noted that students within maritime domain, both in ship design and engineering and maritime operations, are highly interested in understanding human-machine interaction. IT students maintain the focus on their current domain; however, their interest indicates which knowledge in the IT field is seen as most relevant for their future jobs and in relation to MASS. These areas include cybersecurity, artificial intelligence, and computer engineering.

## **DISCUSSION AND CONCLUSIONS**

The study on students' interest in and requirements for MASS-related education presented in this paper provides insights into the expectations for how students' future professions might change and the corresponding needs for such education. First, it is evident that there exists an interest among students engaged in a variety of subjects in pursuing education related to MASS. This interest stems from various factors, including the promising career prospects in this evolving field, an awareness of the potential technological advancements, and an acknowledgement of the growing significance of autonomous shipping in the maritime industry.

Students have indicated a range of motivations for enrolling in MASS-related courses, from career advancement to personal interest in technology. Certain differences in such motivations and the interest in studying particular aspects can be observed among the different student groups depending on their main subject. In particular, future maritime professionals understand the need for basic IT knowledge and are interested in understanding safety and cybersecurity in relation to MASS. Human-machine interaction is yet another pronounced topic of interest. This can be explained by the understanding that the role of seafarers and shipping operators will change together with responsibility, and a certain fear for job security as highlighted in earlier studies (Chan et al., 2023; Theotokatos et al., 2023). Maritime engineering and naval architecture students, in turn, are especially interested in safety, human-machine interaction, but also automation (also in terms of propulsion), which indicates which are the main changes in naval architecture and engineering expected with the advent of autonomous ships. IT students' interests reflect the understanding of which



particular subjects may be applicable in the maritime domain and include cybersecurity, artificial intelligence and automation. The interest of students across subjects to study cybersecurity echoes the expected new safety challenges in the advent of MASS (Bačkalov et al., 2023; Wróbel et al., 2017).

This study emphasizes the importance of curriculum development that aligns with industry trends. Moreover, the study underscores the need for educational institutions to adapt and evolve to meet the changing demands of the maritime industry in the era of autonomous shipping. As MASS is increasingly introduced in shipping, educational programs and institutions must remain responsive to the evolving needs and expectations of the students. This will require more interdisciplinary education and possibly the development of new programs and modules that better reflect new jobs in the maritime industry.

Generally, a good alignment between the student's responses and the findings concerning educational needs for wider MASS implementation derived using expert feedback (see e.g. an extensive study by Bolbot et al., 2022) can be observed based on the research findings. Only a few of the proposed skills in earlier studies were not considered relevant by the students. This can be attributed to the personal interests of the students as well, but overall, it can be concluded that the students demonstrated a good awareness of the required skills in the future. The main contribution of this study is, however, in eliciting the differences in the interests of different student groups based on their main study subject, and a more nuanced analysis of the required interdisciplinary in the education for autonomous shipping from the students' perspective.

## FINANCIAL SUPPORT ACKNOWLEDGEMENTS

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## APPENDIX

Survey questions (the answers to questions marked with \* were used in this study)

1. Age
2. University
  - If other, which educational organisation?
3. Current degree (\*)
4. Field of study (\*)
  - If other, please indicate field of study
5. I am interested in studying courses on Autonomous Shipping (\*)
6. Why are you interested in Autonomous Shipping (choose up to three most important alternatives)? (\*)
  - If other reason, please clarify
7. What aspects of Autonomous Shipping would you like to study? (choose up to four most important alternatives) (\*)
  - If other, please indicate what
8. What is currently restricting you from taking (more) Autonomous Shipping related courses (choose the two most important alternatives)?
  - If other reason, please indicate what
9. Would you like to have more freedom when choosing elective courses?
10. What course(s) would you like to study in addition to your curriculum?
  - I prefer the following way of studying when it comes to Autonomous Shipping related topics (1= theory only; 2= more theory; 3= both; 4= more practice; 5= practice only)
  - I prefer the following way of studying when it comes to Autonomous Shipping related topics (1= lectures only; 2= more lectures; 3= both; 4= more self-study; 5= self-study only)
  - I prefer the following way of studying when it comes to Autonomous Shipping related topics (1= Individual work only; 2= more individual work; 3= both; 4= more teamwork; 5= team work only)
  - I prefer the following way of studying when it comes to Autonomous Shipping related topics (1= online only; 2= more online presence; 3= both; 4= more in-class presence; 5= in-class presence only)
11. In your opinion, what new jobs would Autonomous Shipping create? (\*)
12. In your opinion, which jobs will cease (stop existing) once autonomous ships become more common? (\*)
13. In your opinion, what could be the benefits of Autonomous Ships?"
14. Who should be the Master (captain) of an unmanned ship? (\*)
  - If other, please explain.

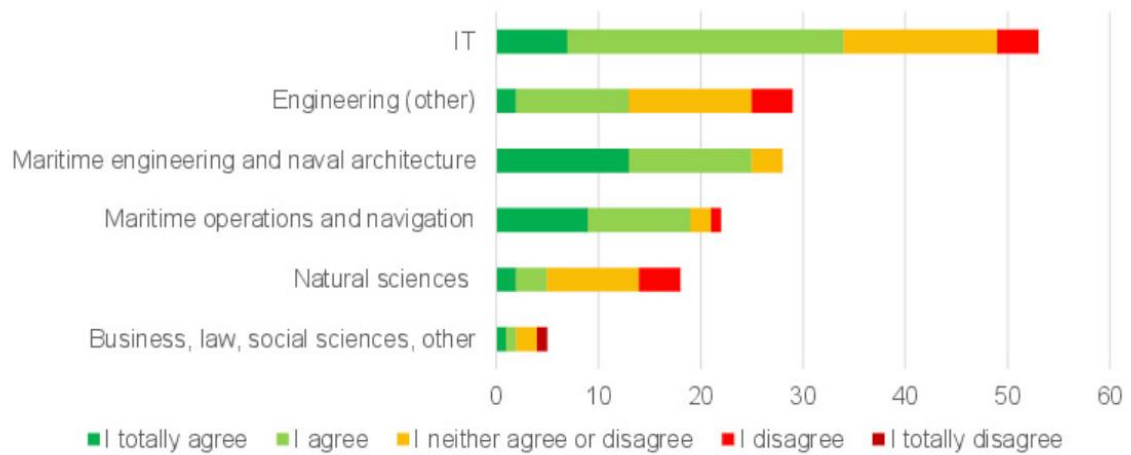


Figure 3. Students' interest in MASS-related education by the current field of study. Responses to the statement: "I am interested in studying courses in Autonomous Shipping" (N = 159)

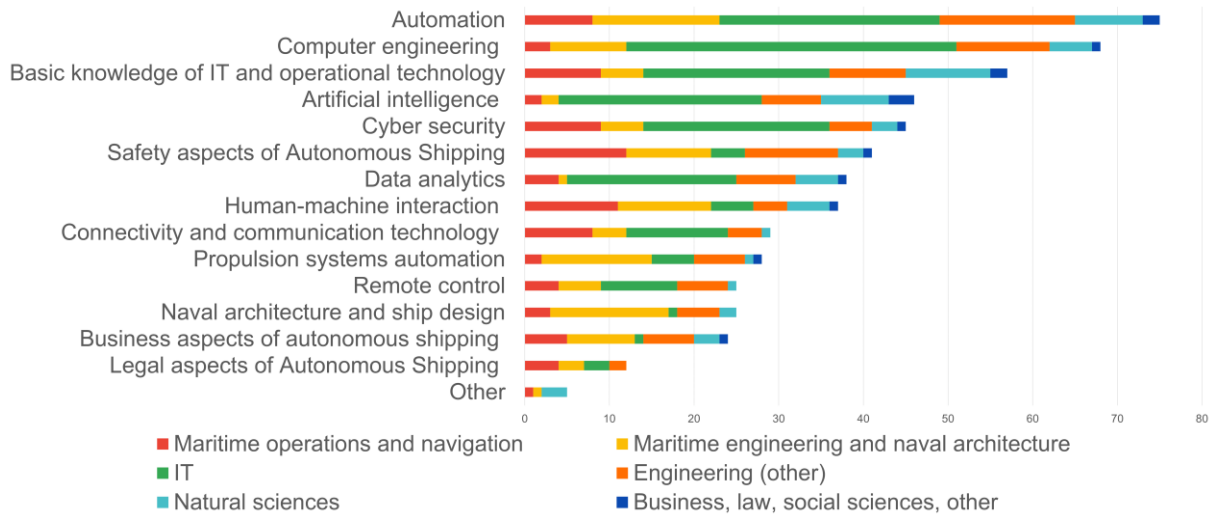


Figure 4. Aspects of MASS-related education that students are interested in studying (N = 159)

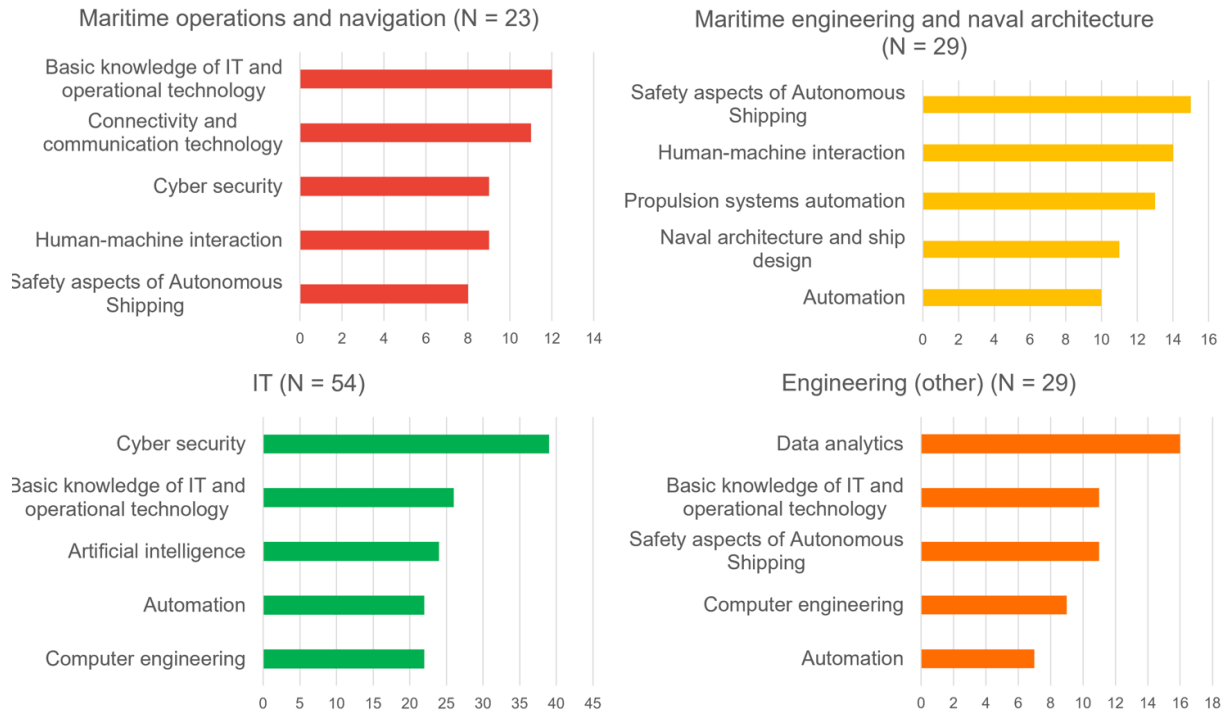


Figure 5. Most relevant aspects of MASS-related education that students are interested in studying separated by four key student groups.

# POTENTIAL PRACTICES FOR ESTABLISHING CURRICULUM AGILITY THROUGH INDUSTRIAL ENGAGEMENT

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## ABSTRACT

The present version of Curriculum Agility is described by 10 principles and is progressing to become a future CDIO Standard. The proposed standard, Curriculum Agility, is designed to be responsive to both future and current industrial requirements with the aim of ensuring that the curriculum contributes to developing so called "industry-ready graduates", i.e., engineering graduates that are competent, capable and confident with respect to technical and employability skills. This paper complements the ongoing work in the CDIO community in creating the optional Curriculum Agility standard. At a workshop on industrial engagement in curriculum agility arranged at the 19th International CDIO Conference in Trondheim, Norway, the participating delegates highlighted both challenges and opportunities. Comments on challenges included, "Are their [industry] perspectives too short? In line with societal needs?" and "[Challenge] the industry to advocate for the future because sustainability is an obligation for us." Comments on opportunities included "[opportunity] bringing in industry, reverence, and authenticity" and "[opportunity for] alumni to provide feedback on courses... on new courses, potential [student] projects... possible research projects." The paper will discuss possibilities for a framework to aid curriculum agility development and enable academic practitioners to effectively engage with industrial partners, recognizing that any learning outcomes of a curriculum need to be constructively aligned with industry's current and future requirements. The curriculum also needs to meet other competing stakeholder requirements, such as those from students, institutions, governments, and relevant Professional Statutory and Regulatory Bodies (PSRB), as well as demands from societal perspectives.

## KEYWORDS

Curriculum Agility, Curriculum Change, quality development. Standards: 2, 3, 5, 7, 8, 9, 10, 11, 12, Optional Standard: Curriculum Agility

## INTRODUCTION

Throughout the world governments have invested in technical institutions and universities during periods of industry revolution, as education became a necessity with a focus on addressing skills development of a workforce for regional economic industrial growth through mass manufacture (Geschwind and Broström, 2020), in addition to craft artisan learning (Wollschlager and Guggenheim, 2004)

However, today it is increasingly recognized that long established higher education engineering degree programs, focusing on technical and employability skills, are out of sync with current and future industry trends (Kamaruzamn, 2019). Half of engineers graduating in the UK lack necessary technical and non-technical skills (EngineeringUK, 2021), and this is also the case throughout Europe (Mannan, 2021). Allan and Rowsell (2017) highlight that engineering education curriculum re-design is critical to supporting the development of engineering graduates that are competent, capable, and technically skilled engineers, that embody professional behaviors with confidence, i.e., 'industry ready' candidates that also are able to challenge current and future unsustainable industrial practices. In the UK, the Engineering Council (2019) Aims for Higher Education Programs 4.0 (AHEP4.0) seek accredited curriculums to deliver world-class education that develops industry-relevant skills. In order to meet the changing demands, curriculums need to be agile in implementing learning opportunities to acquire new skills identified and forecast industry needs (EngineeringUK, 2021).

The world of engineering is changing rapidly, particularly with the dual impact of digitalization and the need to integrate sustainability issues both in education and in practice. Agile modules with flexible learning outcomes that addresses real engineering problems could enable graduates to develop both technical and non-technical competencies (Hart, 2020). Engineering education should be able to address the volatile, uncertain, complex, and ambiguous (VUCA) world through an implementation of a CDIO framework, promoting students to experiment and test solutions to problems (Latha and Christopher B, 2019).

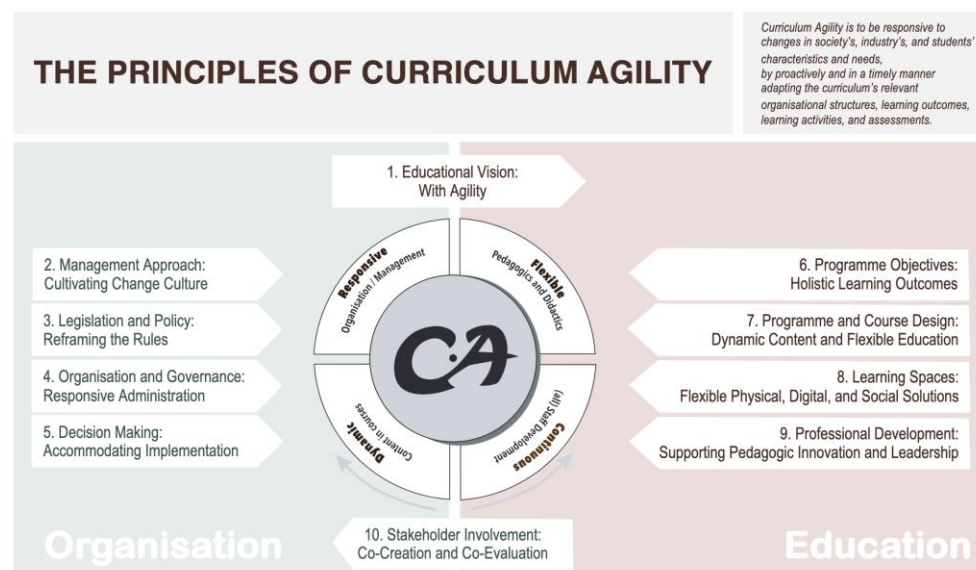


Figure 1. Curriculum Agility and its definition, characteristics, and principles. (Brink et al., 2023)



Curriculum Agility, described by the proposed future CDIO Standard, has the potential to assist engineering curriculum developers in being responsive to market requirements for students, government, and industry (Brink et al., 2020; 2021; 2023), and in the development of a resilient curriculum for the VUCA world (Rouvral et al, 2022). Typically, institutional requirements for academic teams are mandated as part of the quality process for course validation/re-validation, requiring a demonstration of employer engagement in course design.

While universities are struggling to introduce agile practices there are a number of good practices among both public institutions and private companies that provide examples the universities could learn from.

## **LITERATURE REVIEW**

### ***Industrial Advisory Boards***

Established programs and institutions have set up Industrial Advisory Boards (IAB) to assist in developing curriculum quality, equity, diversity, and inclusion, making timely adjustments to courses, and meeting industry requirements (Refae et al., 2016). The development of IAB into an industry partnership, investing in a program, can be mutually beneficial as it potentially yields higher quality graduates for the industry (Guggemos and Khattab, 2015). Such IAB typically consists of institution alumni engineering graduates, industry representatives, and parents of students (McIntyre and Fox, 2014), as well as industry engineering professionals of varying roles or levels (Jones, 2014). Programs are discussed and minuted at Industrial Advisory Board meetings (McIntyre and Fox, 2014), providing timely feedback into the curriculum – an agile approach. Good curriculum design involves industry experts and alumni (Bennett, 2019) with the aim of ensuring that the curriculum is current, future-proofed, and that graduates are employable.

### ***Good Practice: Curriculum Design Revision***

The CDIO community has reported revising curriculum design in response to industrial feedback, for example, to include common industry methods, practices, and management to develop student readiness for the industry (Sparsø et al, 2011). Jørgensen et al (2011) adopted an informal informed industry approach to curriculum program development, gathering requirements from research workshops with industry and academics. The approach of Törngren et al. (2016) to developing an industry-informed curriculum is through industry visits and talks. Kovacs et al. (2023) reported a survey of alumni of graduates from pre-CDIO and post-CDIO curriculum implementation, providing insightful results to inform periodic review and curriculum refreshment: while employers value current curriculum development of students' practical skills, there is a need to further embed employability skills development in the curriculum. In an employer survey Ormazabal et al. (2022) identified that industry valued graduates from courses employing CDIO curricula framework, as these graduates have experience in developing their technical and employability skills, but again it was noted that there is a need for increased skill proficiency.

### ***Requirement Engineering***

Good practice for Requirement Engineering for systems development recommends interviewing professionals individually (Sommerville and Sawyer, 1997). Research into commercial practice for Requirement Engineering found that an informal and semi-formal

Requirement Engineering approach led to more satisfactory software solutions with a greater customer fit (Neill and Laplante, 2003), while Hart (1987) highlighted that knowledge elicitation with a collective of experts in the room risks leading to falsehoods in the knowledge gathered. Therefore, adopting good practice for Requirement Engineering for systems engineering to gather input on industry requirements of engineering graduates and feedback on curriculum design is more likely to yield an informed industry curriculum. Just as with agile software Requirement Engineering, key artifacts can aid the process – for example, user stories, user cases, scenarios, and story cards (Schön et al., 2017), the carpe diem curriculum design approach (Salmon, 2013), or an initial overview of the core course developed by the academic team (Cheah and Yang, 2018).

### ***Identifying Future Competencies***

An alternative agile approach is to horizon scan the engineering community subject area, research activities and outputs to identify technical and non-technical competencies for the future. For example, the Urban Storm- and Wastewater Management research horizon scan has identified emerging curriculum subjects and future competencies of water engineers (Blumensaat et al., 2019). An integrated teaching-research nexus approach to the curriculum allows students to contribute to industry research projects, learn and apply disciplinary knowledge and skills that support their future employment (Magnell et al., 2016). In the UK, two research funding councils (UK RI and EPSRC) have commissioned an investigation into Tomorrow's Engineering Research Challenges Vision (Atkins and Bonfield, 2022), entailing roundtable meetings with numerous stakeholders, including industry Chief Technology Officers; the concluding report provides insights into technical and non-technical skills engineers will require to tackle tomorrow's engineering challenges.

In conclusion, there is a potential opportunity to develop an agile industrial engagement framework to aid academic teams in curriculum agility. A framework that enables academic practitioners to effectively engage with industrial partners, to enable constructive alignment of curriculum learning outcomes with competing stakeholder requirements – industry, students, institutions, Governments, and relevant Professional Statutory and Regulatory Bodies (PSRB), as well as society at large.

## **RESEARCH METHODOLOGY**

The methodology that has been adopted involves using a hybrid agile requirements engineering approach (Kumar et al., 2013) designed as a World Café workshop (Schiele et al., 2022). The World Café workshop on industrial engagement in curriculum agility, arranged at the 19th International CDIO Conference in Trondheim, Norway, provided an opportunity for conference delegates to share their industrial engagement practices with respect to curriculum design. The delegates were asked about curriculum co-creation between curriculum developers and the industry:

- What are the challenges?
- What are the opportunities?

## RESULTS AND DISCUSSION

The workshop was attended by 12 delegates, divided in three World Café tables. Each table was provided with yellow/green post-it notes for opportunities and pink for challenges. Each table was asked to reflect on and identify the challenges and opportunities of co-creating curriculum between developers and industry. Also, they were asked to collate and cluster common reflection themes. The identified common themes from all three tables on the challenges and opportunities are as follows:

- Time and money are both challenges and opportunities for academics and industry, representing potential resources for projects leading to industrially relevant project outputs.
- Horizon scan graduate roles and competencies; IAB with breadth and relevancy (local vs. global).
- Industry engagement brings relevancy and authenticity into the curriculum but also requires industry and academic time.
- Industry is agile compared to academic bureaucracy and 3-5 year degree programs.
- Learning communities, reciprocal learning, and lifelong learning.
- Competing priorities in curriculum design involving students, industry, R&D projects, academics, and academic management requirements.

An appointed table representative summarized their World Café table discussion, identifying key challenges and opportunities themes:

**Table 1:** Reciprocal learning is key to building constructive industry engagement and relationships between academics, students, industry, government parks, non-government organizations, etc. A reciprocal learning environment leads to internships, graduate roles, course co-design, leading to a continuing open-ended environment and relationship in line with the need for lifelong learning for alumni.

**Table 2:** Alumni (course graduates, also academics' own graduate peers in industry) are key to building company contacts and a network to support curriculum co-design as a valuable source of curriculum feedback, CDIO, and research projects.

**Table 3:** Industry engagement can be key to accessing funding for learning opportunities, research, and projects. It represents a symbiotic relationship opportunity to bring challenge, relevancy, and authenticity to the study programs, i.e., sustainability obligation to academia versus an option for industry, real-world problems.

The outcome of the World Café format at Table 1 stressed reciprocity as an opportunity for establishing curriculum agility, in line with several principles in the proposed optional standard for Curriculum Agility shown in Fig.1 (Brink et al., 2020; 2021; 2023). In particular Principle 10 (Stakeholder Involvement: Co-Creation and Co-Development), but also the principles concerning Program and Course Design (7) and Professional Development (9), not only for the students but also for staff.

Table 2 stressed alumni as the bridge between university and work place, providing a network that can engage staff, present and former students, and work places, both public and private in the Co-Creation and Co-Evaluation of Study Programs. This can be related to principle 1 (Educational Vision: With Agility), but likely would also necessitate a discussion of Legislation

and Policy concerning formats for such work (Principle 3: Legislation and Policy: Reframing the Rules).

Table 3, finally, focused on the opportunities for collaboration around learning and research with respect to real-world problems, such as sustainability challenges, which are most often characterized by wickedness and hard to mimic for learning opportunities in textbooks.

Overall, the short session at the 19<sup>th</sup> International CDIO Conference in Trondheim was surprisingly productive in providing a starting point for creating a framework to aid curriculum agility development. There is good reason to trust that future iterations of the World Café approach, possibly accompanied by other agile requirements engineering formats may continue to

## CONCLUSION

The World Café results provided three key points that can be harnessed to support agile industrial engagement activities from curriculum design to curriculum operation:

- Work closely with your alumni, concurring with McIntyre and Fox (2014).
- Build and develop an active industry network and relationships pertinent to the Co-Creation and Co-Evaluation of Study Programs, and also to the development of staff competence.
- Identify and provide reciprocal opportunities, such as talks and industry visits, (Törngren et al., 2016); identify and develop learning resources and projects, (Säisä et al., 2020; Manna et al., 2023); establish internships and graduate roles (Tiewtoy et al., 2019).

While these results were clear, the World Cafe format in this case was found to be limited, however it has been effective in yielding an initial basis, from which further iterations can be made through the establishment of a CDIO working group at regional and international meetings to create a framework.

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# **SERIOUS GAME FOR CDIO DISCOVERING**

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## **ABSTRACT**

The CDIO (Conceive, Design, Implement, Operate) framework is an innovative approach to engineering education. It includes several aspects: the goal of the training program, the syllabus, the content of the training program (Design-Implement Experiences, ...), the continuous improvement in engineering education program, the training practices and the quality management of the training program. Learning about the CDIO framework involves gaining a deep understanding of its principles, standards, and the methodology it promotes for engineering education. The CDIO Initiative's website provides access to valuable information, including the CDIO Syllabus, standards, case studies, and reports. Some universities and institutions offer courses or programs related to CDIO. Enrolling in such courses can provide structured learning and hands-on experience. However, motivating colleagues for CDIO discovery can be challenging. Therefore, we developed a serious game in order to introduce key CDIO concepts. The game structure is based on three questions for each standard: Why? (the intent of the standard) Who? (the main actors of the standard) and How? (the facilities and implemented practices of the standard). During the session, participants share knowledge and experiences about CDIO implementation. The game board is based on a taxonomy of CDIO standards which includes 6 groups of standards: (i) goal of the training program, (ii) contents of the training program, (iii) leaning practices, (iv) learning spaces, (v) teacher training, (vi) training program assessment. To analyze the benefits of the game we developed, we conducted a survey to collect the feedback of workshop participants about their experience and their level of assimilation of the CDIO standards at the end of the session. The data collected highlights the relevance of the game as an activity introducing the CDIO. A large proportion of those questioned stated that they had made progress at the end of the game.

## **KEYWORDS**

CDIO, Serious game, CDIO familiarization, Educational development, Standards: 1-12.



## INTRODUCTION

The CDIO engineering education framework accentuates the cultivation of professional competencies through project-based and experiential learning. The challenges of the industry of the future require pragmatic engineers, combining technological knowledge, innovation, etc. Generally speaking, the main reasons for implementing the CDIO framework included ambitions to make engineering education more authentic, the need for a systematic methodology for educational design, and desires for increased design and innovation in curricula (Malmqvist et al. 2015).

Since Arts et Metiers foundation, AM engineers are known for their spirit of innovation, their excellent technical skills and their ability to manage and cooperate. These well-recognized skills are enhanced by the AM training program which includes theoretical courses and technical projects. Furthermore, Arts et métiers is committed to a competency-based approach as a lever to (i) articulate its program training with social and economic expectations, (ii) match training content to expected competencies and (iii) rethink teaching and learning assessment methods. By joining the CDIO network in 2020, Arts et Metiers would like to benefit from the richness of the network of CDIO members, in order to share best practices and experiences and participate actively in the reflections of the CDIO network related to the evolution of learning practices.

Successful CDIO implementation requires both top-down and bottom-up approaches. The management team can adopt the CDIO framework using top-down methodology that considers institutional vision compatibility with education development goals. The challenges of implementing CDIO involve a shift in mindset, gaining support from faculty members, managing disagreements, and dealing with the additional workload of national qualification standards and accreditation. To address these challenges, the bottom-up approach is recommended (Oien et al 2023). Involving faculty members, program committees, and department heads in the change process boosts intrinsic motivation, fosters a strong commitment, nurtures ownership, and enhances the value of CDIO.

By combining both bottom-up and top-down approaches, Arts et Metiers is relying on stakeholder involvement and the development of a common strategy for CDIO implementation. In fact, Arts et Metiers is an institution spread over several campuses and institutes, which ensures a territorial presence in line with local industrial expertise and powerful relationships with socio-economic actors. However, this value is also a challenge for the establishment when it comes to sharing a common strategy for implementing the CDIO across all its sites. The design of a serious game based on a common vision of the CDIO and its implementation processes allows the actors of the different sites to appropriate the key CDIO principles and their declination into a set of actions to be deployed.

In this context, we have developed a serious game for faculty members to take ownership of CDIO. The game design involved several actors, including a teacher with in-depth knowledge of CDIO, an instructional designer, and the Vice-President for Academic and Student Affairs. We tested the game with a group of teachers in July 2023 and rolled it out from September 2023.

The “game outcomes” are:

- 1) To distinguish the objectives associated to each of the 12 CDIO standards
- 2) To identify the actors involved in each CDIO standard
- 3) To outline the actions to be made in order to implement each CDIO standard

This paper is organized as follows: Section 2 introduces the adopted serious game design methodology. Section 3 details the CDIO standard taxonomy for designing the game board. The description and the rules of the serious games are summarized in Section 4. The final section includes the player feedbacks and a discussion.

## SERIOUS GAME DESIGN METHODOLOGY

Developing serious games about CDIO (Conceive, Design, Implement, Operate) requires a thoughtful approach to integrate content with engaging gameplay. We use the generic **DICE model** (Djaouti, 2011) to design our serious game (Figure 1). The Define step begins with the definition of the learning outcomes: expected skills of the players – The players are faculty members; the goal is to learn about the CDIO standards: 1) the **purpose** of each CDIO standard, 2) the **roles** of each actors in the CDIO implementation, and 3) the **Arts et Metiers practices** which are aligned with CDIO principles.

Following this definition step, start an iterative cycle with 3 different steps:

- The **Imagine step** request to mobilize the CDIO Principles: to ensure a solid understanding of the CDIO framework, we performed an extensive bibliographic analysis of CDIO principles and standards, we developed a **taxonomy of CDIO standards** based on the Arts et Metiers organization.
- The **Create step** focus on the design of the game with the players in mind and made the gameplay challenging but enjoyable. **Interactivity** is crucial for engagement and effective learning in serious games. To increase interactivity and collaboration, we selected a team-based gameplay. We defined a well-structured progression system: The game structure is based on three questions for each standard: **Why?** (the intent of the standard), **Who?** (the main actors of the standard) and **How?** (the facilities and implemented practices of the standard).
- The **Evaluate step** consist in providing a feedback session. Actually, at the end of the game, participants are invited to discuss the key points that they have retained and misunderstood elements to be clarified. They are also requested to complete a survey to gather feedback on their **experience of the game**.

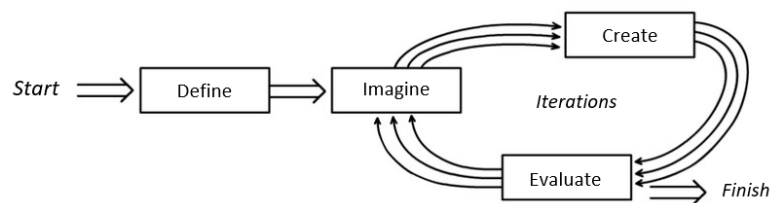


Figure 1. The generic DICE model of the Serious Game Design process (2011, Djaouti, p.105)

## GAME BOARD BASED ON CDIO TAXONOMY

It is recommended to provide a visual representation of the standards to facilitate the exploration: A CDIO standard taxonomy. The most known CDIO taxonomy (Figure 2A) is that developed by Brodeur and Crawley (2005); they listed the correspondence between the 12 CDIO Standards and key quality assurance questions:

- **Standard 1 CDIO as Context and Standard 2 CDIO Syllabus Outcomes:** What are objectives and outcomes of a CDIO program? How are they aligned with institutional mission and program goals? What is the context for these objectives and outcomes?
- **Standard 3 Integrated Curriculum:** How does a CDIO curriculum contribute to the attainment of program outcomes? How are CDIO outcomes embodied in the CDIO Syllabus integrated into the curriculum?
- **Standard 4 Introduction to Engineering:** How do first-year courses introduce the CDIO context and motivate students to choose engineering programs?
- **Standard 5 Design-Implement Experiences, Standard 7 Integrated Learning Experiences and Standard 8 Active Learning:** How do active and experiential methods contribute to the attainment of program outcomes in a CDIO context? How are these learning experiences integrate into the engineering program?
- **Standard 6 CDIO Workspaces:** How does the learning environment contribute to the attainment of CDIO program objectives and outcomes
- **Standard 11 CDIO Skills Assessment:** What have students achieved with respect to program outcomes? How are CDIO learning outcomes measured and documented
- **Standard 9 Enhancement of Faculty CDIO Skills and Standard 10 Enhancement of Faculty Teaching Skills:** How are faculty development and motivation encouraged? How do faculty roles change in a CDIO context? How satisfied are faculty with the teaching and learning experiences?
- **Standard 12 CDIO Program Evaluation:** Is there a systematic process in place to evaluate CDIO program outcomes and processes? Are the evaluation results used in continuous process improvement?

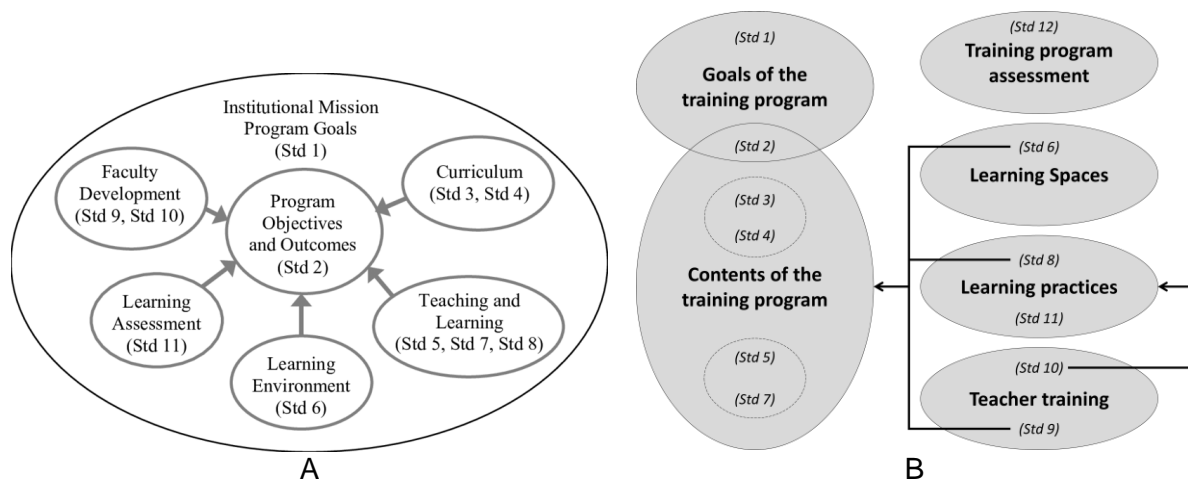


Figure 2. CDIO Standard taxonomy

Based on the CDIO understanding and the Arts et Metiers practices, we propose a taxonomy of CDIO standards which includes 6 groups of standards: (i) goal of the training program, (ii) contents of the training program, (iii) leaning practices, (iv) learning spaces, (v) teacher training, (vi) training program assessment.

The main point of the serious game is to discover and to analyze the scopes, the vision and the aims of all CDIO standards based on (Crawley et al, 2014), (Malmqvist et al, 2020) and (Malmqvist et al, 2022). In order to achieve this, the game board contains a taxonomy of CDIO

standards and one question for each standard that summarizes its goal (Figure 2B). The correspondence between the 12 CDIO Standards and 12 questions is listed below:

- **Standard 1: Why?** In fact, this standard includes the program goals which are the answer to the question: why this training program?
- **Standard 2: What? and Where?** The standard 2 focuses on the syllabus: specific, detailed learning outcomes for personal and interpersonal skills, and product, process, system, and service building skills, as well as disciplinary knowledge. What is the learning outcomes of the training program? Where, in which course?
- **Standard 3: When?** The curriculum includes the sequencing courses and projects, that is designed with mutually supporting disciplinary courses and an explicit plan to integrate personal and interpersonal skills, as well as skills in product, process, system, and service building. When each course is planned?
- **Standards 4, 5 and 7: How?** These standards focus on key contents of the training program: (i) an introductory course that provides the framework for engineering practice, (ii) two or more design-implement experiences, and (iii) integrated learning experiences. How to achieve the learning outcomes and the goals of the training program?

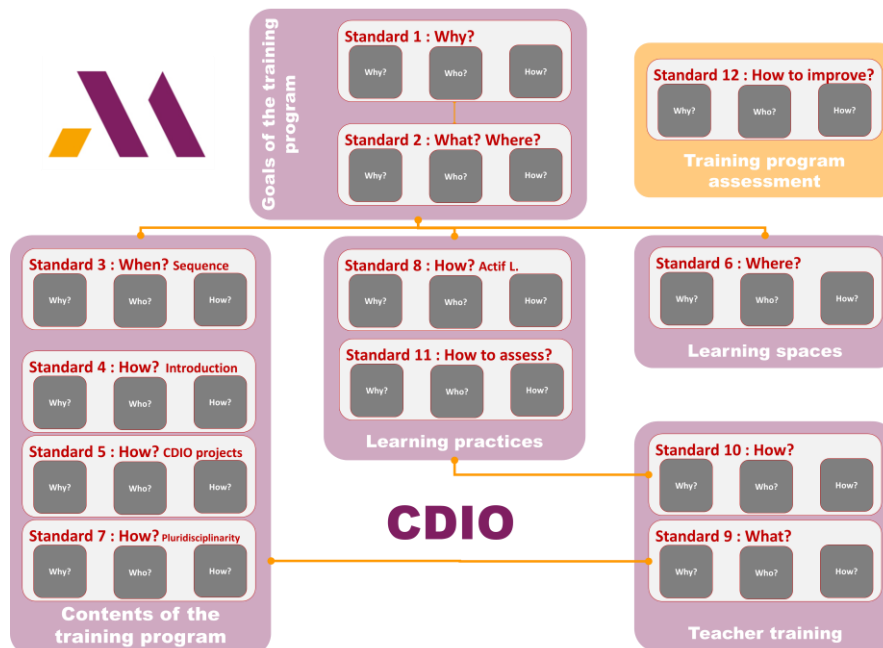


Figure 3. CDIO game board

- **Standard 6: Where?** The standard 6 is dedicated on the engineering learning workspaces - A physical learning environment that includes engineering workspaces and laboratories. Where each course is performed?
- **Standard 8: How?** The standard 8 focuses on the learning practices: active learning - Teaching and learning based on active and experiential learning methods. How to engage students directly in thinking and problem-solving activities?
- **Standard 11: How to assess?** How to measure the extent to which each student achieves the intended specified learning outcomes? In fact, the standard 11 deals with learning assessment.
- **Standards 9 and 10: How and What?** These standards focus on teacher learning: (i) actions that enhance faculty scientific and technical competence, and (ii) actions that

enhance faculty competence in providing integrated learning experiences, in using active and experiential learning methods, and in assessing student learning.

- **Standard 12: How to improve?** How to measure the judgment of the overall value of a program based on evidence of a program's progress toward attaining its goals.

## DESCRIPTION AND GAME RULES

The serious game includes a game board (Figure 3), 36 game cards divided into 3 questions categories: Why? the intent of the standard, Who? the main actors of the standard and How? the facilities and implemented practices of the standard. To clarify the aim of each standard, players are asked to place each of the three questions cards in the appropriate standard box.

The participants are invited to place on the board: first the “why?” cards which help them to understand the purpose of each standard, then the “who?” cards to identify the actors involved in the standard and finally the “how?” cards to find out what actions they need to implement.

The game is played by a team and typically lasts between one and a half to two hours. The first team pick a card, addresses the team to its right and reads the statement on the card. If the challenged team identify the standard corresponding to the card, it wins a point and the card is placed on the correct box; on the contrary if the team does not answer correctly, the card is placed back under the stack of cards and it is the next team's turn to play. When all cards have been placed on the board, the team with the highest score wins the game.

## PLAYER FEEDBACKS AND DISCUSSIONS

Our analysis of the serious game that we have developed aims to establish if the playful format and game mechanisms contribute to the appropriation of the CDIO framework by the participants. To achieve this goal, we are using the results of a survey based on the first and second levels of the Kirkpatrick model (1994): the first level focuses on experience and satisfaction and the second level on learning. In addition to closed questions, the surveys include open questions to collect feedback about strengths and improvements to be made in the future.

The results we present are based on 31 responses to survey administered following five workshops (game sessions). We organized two workshops in Paris with actors from our different sites, the third in Cluny, the fourth in Bordeaux and the fifth at Aix-en-Provence (Figure 4 Left). 83% of respondents indicated they had a good gaming experience in the CDIO Game (Figure 4 Right). Based on the feedback from the workshops (Figure 5), we note that 81% of the respondents think that this game is a good way to understand what the CDIO is. 90% enjoyed using a game to discover the CDIO and they all agree (100%) that "the exchanges with other participants were rich and useful". 94% of respondents said that the effort and time spent were balanced, and 87% of respondents said that they played the game in good conditions (organisation, order). On the statement "The game provided me valuable examples of action that I can apply", opinions are more divided: 49% of respondents agreed and 51% disagreed. However, 45% related the game doesn't provide them enough examples.

Afterwards, we focus on the second level of the of the Kirkpatrick model, which is a measure of respondents' learning progress at the end of the game (Figure 6). Respondents self-assess their level before and after the game on a scale from 0 (not at all able) to 10 (fully capable).

The data collected illustrates progress in three learning objectives (LOs): 1) distinguish the objectives associated to each of the 12 CDIO standards, 2) identify the actors involved in each CDIO standard and 3) outline the actions to be made in order to implement each CDIO standard.

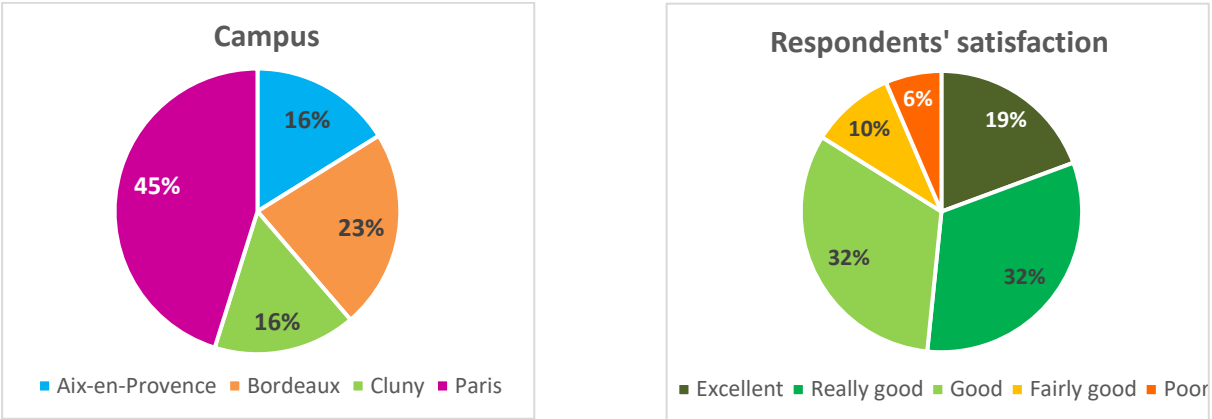


Figure 4. *Left:* Geographical breakdown of respondents by campus. *Right:* Respondents' satisfaction

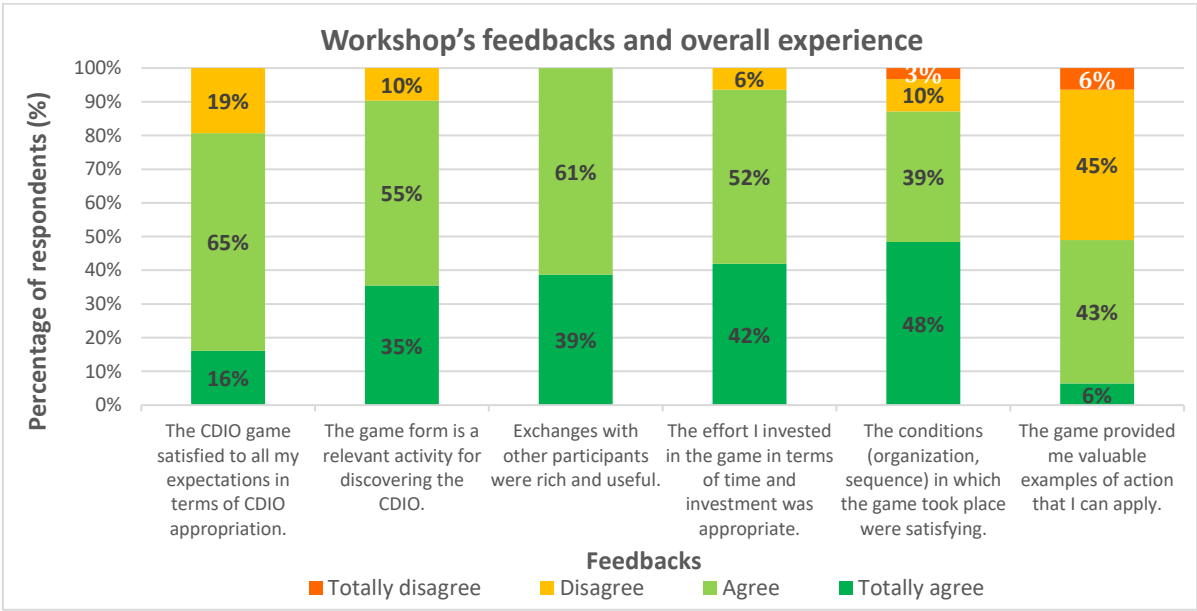


Figure 5. Workshop's feedbacks and overall experience

The total number of respondents for this survey decreased from 31 to 29 as two respondents did not answer this section. Out of the 29 respondents, two did not indicate their progress on one of the assessed items. 86% of the respondents reported making more than 51% progress on the first learning outcome objective, while only 14% felt they had made little progress (below 50%). As for the second learning outcome, 61% of the respondents reported strong progress (over 75%), while 32% felt they had not made as much progress (under 50%). It is worth noting that this objective is the one on which respondents reported the least progress. Finally, 75% of the respondents answered that the CDIO game was a means to initiate discussions about the CDIO implementation and the Arts et Metier practices.

The verbatims collected from open-ended questions allow us to identify several strengths in the game. Respondents appreciate the “playful” side of the workshop; this term was mentioned several times which they thought made the workshop “friendly” and “interactive”. In fact interactivity is a point we develop during the creation phase according to the DICE model (2011, Djaouti). They also emphasize the interest of playing as a team and the duration of the workshop adapted to their busy schedule as the following comments underline:

- “Exchange with the various players in the game”
- “Playing as a team”
- “We can do it quickly, which is important given our busy schedules”

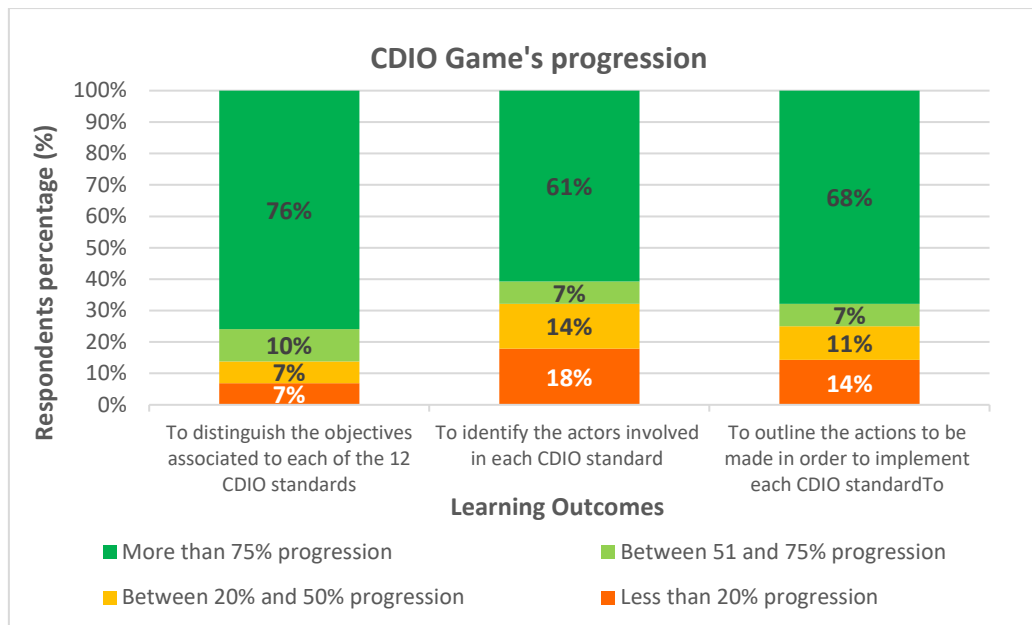


Figure 6. CDIO Game’s progression

Participants even highlight the fact that the game is adapted to participants with different levels of knowledge of the CDIO which promotes exchanges as expressed by one of the respondents “Fun and easy initiation for all levels”. Another highlight of the workshop is its adaptation to the context of the institution Arts et Metiers, which provides concrete elements that help to understand the standards and their mode of deployment.

- “It’s a practical way to get started, and it’s adapted to Arts et Métiers context”.
- “It helps us to understand the purpose of certain issues (teaching assessments, semester committees, best practices for introducing a course, etc.) for which some colleagues are questioning the relevance”.

Regarding improvement points, participants' responses had a limited reference to the form of the workshop as a game and focused mainly on fundamental questions relating to the understanding of CDIO and its deployment. As mentioned on the following comments, the game enables the participants to discover the standards, but it requires further concrete actions to deploy each standard. “Emphasize post-game exchanges to discuss the “who” and “how” that may not be clear to everyone.”, “Not easy to know how to use on a daily basis in my field”. In particular, participants underlined the efforts required to identify and converge to the same actors involved in each standard.

Concerning the game, the respondents emphasize that the questions on certain cards are hard to apprehend and to link to a specific standard “cards and board labels are sometimes very complex to understand”, “the "why" questions are difficult to answer, as the instructions on the board are not detailed enough». They suggested rewording the questions on certain cards and providing more concrete examples.

To improve our game in the light of our serious game methodology proposed by Djaouti and our survey results, we notice we need to be more specific about the learning outcomes of the game, in order to answer to all expectations in terms of understanding the CDIO (Define step). We remind that the aim of the game presented here is to help participants to discover the CDIO and how it works which is necessary before considering a level 2 of the CDIO game more focused on actions to be deployed.

The feedback from participants confirms that a boardgame with cards is a relevant way to discover the CDIO standards. It's requires a few equipment and time to play given the complexity of the subject. Nevertheless, some participants may find the game more challenging than others, the first step with Why? cards, is the longest of the game: it is the time to understand the rules of the game and the content of the cards. However, there's a change when they start to place the other cards (Who? et How?) because they can use the previous cards to help them. The game mechanics defined during the create step mean that the game encourages exchanges between participants according to the survey.

## CONCLUSION

The analysis of the data we collected underlines the value of introducing a workshop in playful form as a support in deploying the CDIO in a multi-site establishment. Setting up the same workshop on all campuses means sharing the same framework and common vision for CDIO deployment. The playful aspect of the workshop, takes place for a short time, encourages the participation of all actors, in a convivial format that promotes exchanges between participants.

In terms of CDIO appropriation, the feedback we have collected from participants concludes that the serious game we have designed can be considered as a first step in discovering CDIO principles. In order to continue supporting the community in the deployment of the CDIO, we plan to design a level 2 that will enable them. The aim of level 2 is for players to propose several improvements for each standard deployment.

In terms of the actions taken to measure the impact of the game on participants' knowledge, we based our assessment on respondents' self-reporting of the workshop's learning objectives. To measure the impact of the game more effectively, we plan to set up a knowledge test before and after the game to assess participants' progress.

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# **CDIO METHODOLOGIES IN FIRST-YEAR PROJECTS OF MECHANICAL, CHEMICAL, AND FOOD BIOPROCESSES ENGINEERING**

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## **ABSTRACT**

This work delves into the integration of CDIO principles within first-year integrated group projects, highlighting collaborative efforts within discipline-specific groups, diverse project deliverables, and the unique emphasis on the Project Showcase for assessment. The integration of CDIO has been applied to methodologies within first-year integrated group projects in Mechanical, Chemical, and Food Bioprocesses Engineering. Students collaboratively conceive solutions to engineering challenges within their respective disciplines. The group dynamic fosters creative thinking, problem-solving, and discipline-specific collaboration. The projects involve diverse deliverables, with the final assessment placing a higher weight on the collective group performance during the Project Showcase. This live demonstration is a pivotal evaluation moment, integrating CDIO principles into a real-world context. The showcase not only provides a platform for students to communicate their design rationale, operational strategies, and project outcomes to a broader audience but also places a heightened emphasis on the collective group performance during this interactive and operational presentation. Graduates emerge with not only technical proficiency but also with the invaluable skills of teamwork, communication, and adaptability, which are essential attributes for success within their chosen engineering field.

## **KEYWORDS**

Integrated group projects, First-year students, CBL, Engineering, Public showcase, CDIO, Standards: 1, 3, 4, 6, 8, 11

## **INTRODUCTION**

The first year of engineering studies lays the groundwork for students' future professional paths (Lakin et al., 2020), which is why the decision is made to incorporate CDIO principles into integrated group projects for first-year engineering students (Karhunen, 2008).

In the first year of their academic journey, students often express concerns about the predominantly theoretical nature of their studies, perceiving an imbalance with practical application (BOE-A-2021-15781, 2021). The implementation of integrated projects based on the CDIO philosophy has emerged as a solution to this challenge. Pereira et al. (2017) demonstrate how integrating projects can bridge the gap between fundamental or theoretical course subjects, leading to a more practical approach and ultimately enhancing student satisfaction. These projects provide students with the opportunity to witness, from their first year, how the theoretical concepts they are learning directly apply to real-world situations (Saeidlou et al., 2023). By addressing real problems and working on the conception, design, implementation, and operation of solutions, students find meaning and practical applicability in what they are learning. Siew Ping et al. (2010) also shows that the project facilitates the conceive-design process and helps integrate knowledge from different modules together without needing any extra resources. Consequently, the implementation of these projects catalyzes a more enriching and motivating educational experience (Alpay et al., 2008) right from the beginning of their academic journey.

The benefits of these projects extend to first-year students by providing them with a practical and collaborative educational experience. Alaya et al. (2017) demonstrate how this activity improve their personal and technical skills. It allows them to apply the knowledge acquired through solving real-world problems, fostering creative thinking and teamwork skills (Vijayarajam, 2012). Moreover, as Jonassen et al. (2006) says, practicing engineers are hired, retained, and rewarded for solving problems, so engineering students should learn how to solve real-world problems. Real-world engineering problems are substantively different from the kinds of problems that engineering students most often solve in the classroom; therefore, learning to solve classroom problems does not necessarily prepare engineering students to solve workplace problems. This project, within the CDIO framework, helps students develop a comprehensive understanding of the engineering creation process and acquire essential skills to address real-world challenges (Wordley et al., 2023).

The culmination of the project with a public presentation not only serves as a final assessment but also enhances students' motivation. The dynamics of the public presentation foster competition among groups to achieve outstanding solutions and bring out the best in each team. Group competition acts as a positive stimulus; students strive to excel and overcome challenges, contributing to a dynamic and engaged learning environment. Therefore, a culture of collaboration is promoted, where the individual success of a group translates into collective success, emphasizing the fundamental principles of CDIO that advocate collaboration and teamwork in the field of engineering (Goh et al., 2023; Siegkas, 2021). Teo et al. (2013) demonstrates how students are motivated and engaged in participating through an integrated project that leads to an exhibition and competition. Furthermore, beyond its immediate impact on students during presentations, this dynamic also equips them with tools for the future. The public presentation at the end of the project underscores the importance of communication and results presentation, preparing students for success in their future endeavors.

This work outlines the integrated projects in three academic disciplines, mechanical engineering, chemical engineering, and food bioprocess engineering programs. In mechanical engineering, this project is implemented in the subject Integrated Project I (Projecte Integrador I - 20224125) which is part of the second term of the first year of the undergraduate program of Mechanical Engineering Bachelor from Universitat Rovira i Virgili (URV). The Integrated Project (IP) subject intend to force the students, to put into practice the knowledge acquired in some of the core topics of the Mechanical Engineering program. In the first year, the IP deals with basic Physics, Mathematics, Engineering Design with emphasis in Computer Aided

Design, and computer programming. The IP has 6 ECTS credits, with a total workload for the student of 150 h. A 30% of these (45 h), are developed in-person with the professor in the classroom. In the case of chemical engineering and food bioprocess engineering, the subject pertaining to integrated projects is "Fundamentals of Process Engineering," encompassing a total of 9 ECTS. Of these, 6 ECTS are directly allocated to project implementation, while the remaining 3 ECTS focus on in-class theory, providing the necessary knowledge for effective project execution.

The proceeding begins with a presentation of the methodology used, detailing the approach applied at each degree and including an example of its implementation. Following this, the results section reflects student opinions regarding the initiative, particularly within the framework of the CDIO syllabus. Finally, the limitations and conclusions are exposed.

## **METHODOLOGY**

This project has been ongoing for several years, and each year the statement is modified to be aligned with the engineering context and updated (Standard 1). Despite changes in the statement, the desired objectives remain consistent, and the purpose of the project stays unchanged. The objectives of the projects are:

- Execute the project to facilitate the effective integration of competencies developed in various subjects.
- Develop a practical study on obtaining a product from raw materials, thereby fostering the student's capacity for analysis and synthesis in the design of a manufacturing process.
- Present a functional machine that successfully passes a public test, considering this achievement as crucial for the approval of the subject.
- Promote teamwork, interdependence, and the development of technical and social skills in the student.

After establishing the objectives, the implementation strategy varies between the Mechanical Engineering program (BSME) and the Chemical (BSQE) and Food Bioprocess Engineering (BSFB) program.

### ***Methodological Framework for Mechanical Engineering Integrated Projects***

The course is distributed over a term of 15 weeks (3 h/week), 1 h for theoretical lectures (all students) and 2 h for laboratory activities, where students are divided into smaller groups with a maximum of 20 students per group. The theoretical presentations (T1 to T10) deal with product design concepts such as: Product planning, customer needs identification, product specifications, concept generation, proof of concept, industrial design, need for prototypes, product management, etc (Standard 8). During the course, there are also programmed two seminars (S1 and S2) that deal with gender equality. These seminars are taught by experts in the matter from the humanities department at URV. A tentative weekly planning is included in table 1 for reference.

Table 7. Weekly planning of BSME project.

| Week | T (1h)                                  | h | LAB (2h)           | h |
|------|-----------------------------------------|---|--------------------|---|
| 1    | Presentation / Outline                  | 1 |                    |   |
| 2    | Problem statement E1                    | 1 | Tutorial E1        | 2 |
| 3    | T1                                      | 1 | Tutorial E1        | 2 |
| 4    | T2                                      | 1 | Tutorial E1        | 2 |
| 5    | Deliverable E1/ Problem statement E2    | 1 | Tutorial E2        | 2 |
| 6    | T3                                      | 1 | Tutorial E2        | 2 |
| 7    | T4                                      | 1 | Tutorial E2        | 2 |
| 8    | T5/Deliverable E2/ Problem statement E3 | 1 |                    |   |
| 9    | T6                                      | 1 | Open fab. lab      | 2 |
| 10   | S1                                      | 1 | Open fab. lab      | 2 |
| 11   | S2                                      | 1 | Open fab. lab      | 2 |
| 12   | T7/Deliverable E3                       | 1 | FINAL presentation | 2 |
| 13   | T8                                      | 1 | FINAL presentation | 2 |
| 14   | T9                                      | 1 | Prototype testing  | 2 |
| 15   | T10                                     | 1 | Prototype testing  | 2 |
| 16   |                                         | 1 | FINAL CONTEST (E4) | 4 |

The subject is organized around the main project, that implies the conception, design, implementation and operation (CDIO) of a device to solve a challenge posed by the professors. Students form groups of around 5 individuals, that work together to solve the challenge. The problem is introduced and described in a progressive manner by means of several problem statement lectures (E1 to E4). Figure 1 shows that the different execution phases of the course project (E1 to E4) can be linked to the CDIO principles.

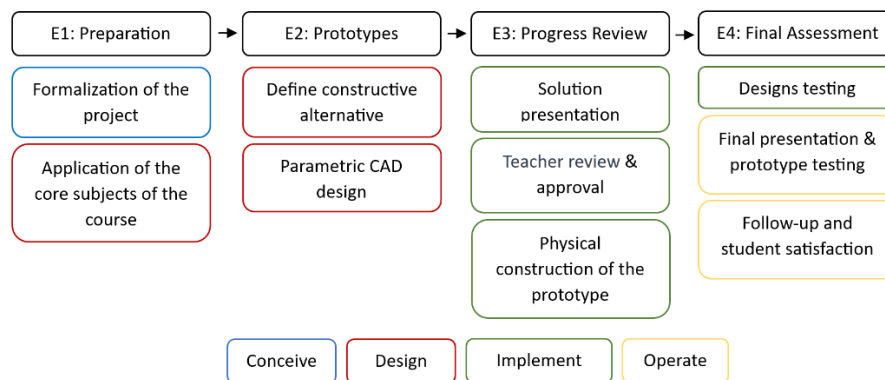


Figure 4. CDIO principles in the execution phases.

The first problem statement (E1) is the formalization of the project which involves establishing, in a clear and detailed manner, the essential aspects. This formalization includes defining objectives, identifying requirements, developing the work plan and assigning roles and responsibilities. Student can formalize this part thanks to the statement of the project. The statement also establishes certain size limitations restrictions and the way it has to be manufactured. During the formalization of the project, students are also working on conceptualizing the project from the perspective of physics and mathematics (Standard 4). The task focuses on forcing the students to work the physics, describing the parameters to consider and to derive the equations that govern the problem, thus providing a practical application of the concepts learned in theoretical classes. They end up delivering a report with all the

theoretical considerations, as well as numerical solutions of the expressions found, and their graphical representations.

In the second problem statement (E2), students define constructive alternatives to implement the parameters they calculate in the preceding stage and formulate different solutions. They define a design and use parametric CAD tools such as Autodesk Inventor, to implement it. Finally, they generate a final design report that includes the analysis of alternatives and the engineering and manufacturing drawings of the device. The next stage is the presentation of the solution in front of all other students and professors. Students are required to prepare an oral presentation, summarizing the reports presented for E1 and E2. Once this stage has been finished and approved by the professors, students can start the manufacturing of the device. During the physical creation phase of the project, students have access to the laboratories (Standard 6). Finally, students have the opportunity to test their designs prior to the final competition. The idea of the testing stage is to put into practice the theoretical findings to see if it works as expected or there are experimental deviations that can be corrected with calibration, or if they need to redesign small parts of it. The testing implies quantitative measurements. In the final presentation, all groups are assessed in a public exhibition open to anyone interested. Each group brings its prototype and undergoes various tests in an area of the university adapted to the statement. Before conducting tests on the prototype, a representative from each group gives a brief presentation of the team and the work to share the entire project process.

The final grade of the subject (Standards 11) is obtained from the partial grades obtained from reports E1 and E2, the oral presentation E3 (all three accounting for a 35% of the final grade) and the performance achieved in the final competition (accounting for a 35% of the final grade). The other 30% of the grade comes from 2 different tests that deal with the theoretical contents of the subject. In the academic year 2022/23 the challenge posed to the students was to design a machine to shoot a tennis ball to a basketball board, configured at a certain height and at different distances. The machine had certain size limitations restrictions, and needs to be manufactured using basic operations, therefore welding, advanced manufacturing, or CNC are not allowed as they will learn all this processes in third year. The energy to throw the ball needs to come from potential energy, that is also limited by the problem statement.

Table 8. Specific example of the BSME methodology.

|    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| E1 | The problem statement is provided, and students carry out the formalization of the project to understand all aspects required by the task. Additionally, in the report, students are also required to integrate theoretical concepts. They had to provide the expressions of the horizontal and vertical position of the ball as a function of time, along with the trajectory and the initial speed of the ball in relation to the throw angle. Moreover, in this case, they had to calculate the optimal angle for each distance and height to the basketball board. Students are required to code using MATLAB to produce this initial report. Some of the results to this initial stage of the problem appear as an example, in figure 2, as implemented by the professor. |
|----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

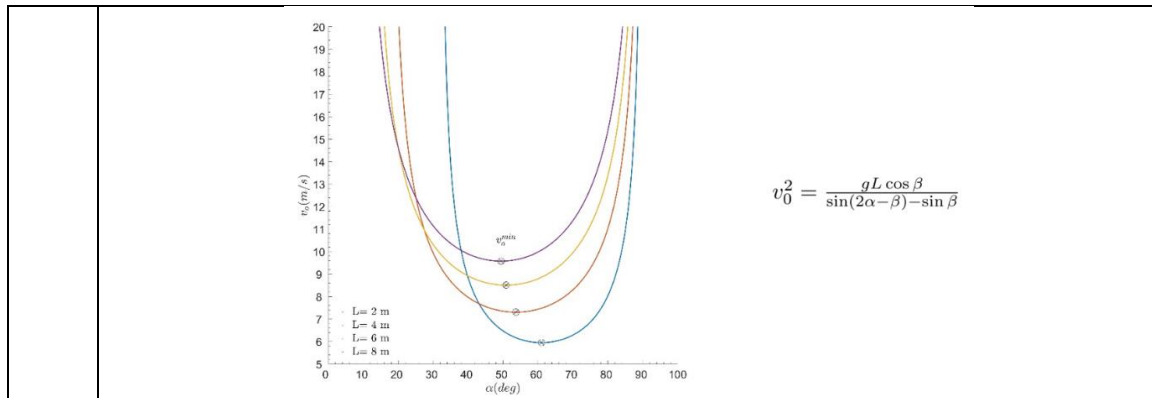


Figure 5. Initial stage of the problem.

In the second problem statement (E2), students define constructive alternatives to implement the solutions found in the previous stage. An example of one of the drawings generated by one of the groups, appears in figure 3 (Standard 3).

E2

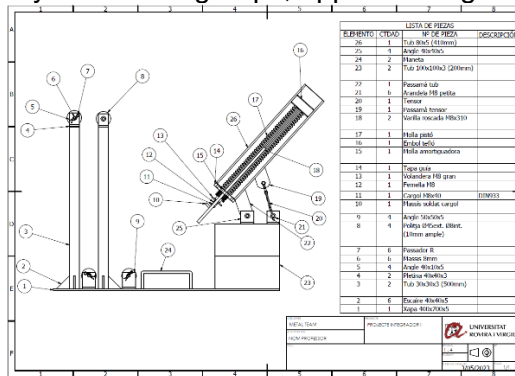


Figure 6. Example of one of the drawings generated.

E3

They present the solution to the professors and other groups. Once approved by the professors, students start the manufacturing of the device.

E4

Teams start testing their prototype, measurements were obtained using image analysis of the tennis ball thrown to compute velocity and trajectory. After the testing period, there is the final competition, where students show up the performance of their devices. In the final contest, each team had to perform 5 ball throws, 3 at fixed distances of 8, 6 and 4 m, plus two more of their election, between the three previous distances. The maximum score was only achieved when the ball entered the basket, but lower scores were obtained depending on where the ball touched the basket board, that was divided in a 3x3 array of areas. No score was given in the case of missing the board or the basket. The 5 throws led to an average score that ranked all the teams. An image of one of the teams throwing the ball with their invention appears in figure 4.

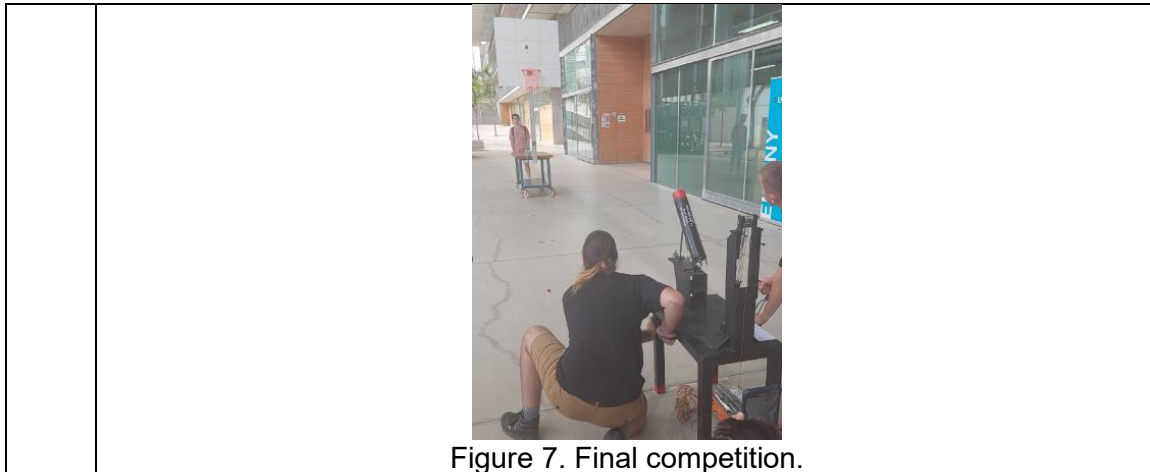


Figure 7. Final competition.

### **Methodological Framework for Chemical Engineering (BSQE) and Food Bioprocess Engineering (BSFB) Integrated Projects**

The integrated preliminary project of the first year (API1) in Chemical Engineering (BSQE) and Food Bioprocess Engineering (BSFB) is based on the execution and coordination of several organized activities. Figure 5 shows the relationship between these activities and the CDIO fundamentals.

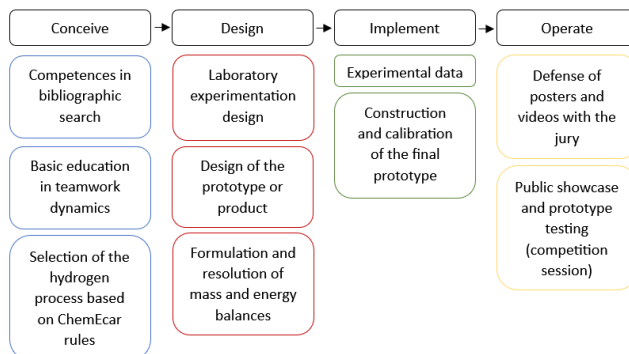


Figure 8. CDIO principles in the activities.

The objective of API1 in every degree is:

- Conceive, design, implement, and operate a vehicle powered by a chemical process (Chem-E-Car, BSQE).
- Conceive, design, implement, and operate an innovative, eco-friendly, and marketable food product (Food Challenge Design, BSFB).

The initial stage involves providing students with all the necessary tools to carry out the project (conceive). An initial training session by the university library staff is scheduled to introduce the use of the digital library of the university, the search engine, and the catalog, as well as a description of the concepts and uses of Manuals, Encyclopedias, Scientific Journals, etc. Moreover, a set of techniques and methodologies is introduced that allow building human teams that are more cohesive and motivated to fulfill their tasks. Under the principles of complementarity and solidarity, the members of a team feel more confident to tackle any project, they feel more satisfied when they work, they achieve their goals more efficiently and



with higher quality. Likewise, they must draw up a Team Charter for the team, under the direction and advice of the corresponding leader. Once they have settled the group, teams have to choose the product or groups of products on which the overall API1 will be developed, which must be directly involved in the propulsion of the vehicle or the execution of the food product.


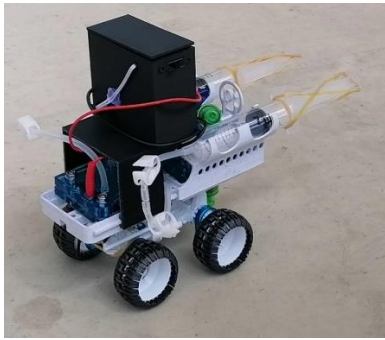
Once the project foundations are set, teams start the design phase. The team plans a simple laboratory experiment that allows characterizing some aspect related to the propulsion of the vehicle or the creation of the food product (Standard 8). This experiment must be chosen and prepared according to the availability of resources in the laboratory and must be planned meticulously under the supervision of the laboratory supervisors. Teams have laboratory sessions (Standard 6) to carry out the scheduled experimentation and at the end, they prepare a report summarizing the results of the laboratory experiments. In order to grasp all theoretical concepts, teams conduct an extensive bibliographic search on the chosen product, covering: a) Its properties, uses, industrial production, and other relevant aspects such as handling or storage conditions (product datasheets) b) Existing or possible production processes, their locations, capacities, and pertinent characteristics. The design of the vehicle or the food product is started as soon as they feel capable of doing so, simultaneously engaging in the tasks described in this phase.

During the implementation phase, the teams develop a graphical description in the form of a block diagram and a report of the selected process. They also formulate and solve the relevant material balances for individual operations and the overall process. The results are presented in the form of a numerical table attached to the block diagram, specifying flow rates and operating conditions for a given calculation basis. Finally, each team plans and executes the construction of a vehicle (BSQE) or the development of a food product (BSFB) according to the specified characteristics and requirements. During this phase, the teams have access to the laboratories. Finally, the team presents a final report, a descriptive video of the construction and configuration of the vehicle or the food product, as well as a poster for the public presentation.

The day of the showcase, the groups give a presentation and publicly defend the results of the report through the display of the poster and video. During the public presentation session, open to all interested parties, all team members are interviewed by the professors, who will provide individual assessments. Additionally, two professional juries examine the presented works and evaluate them, awarding prizes to the best projects in each specialty, BSQE and BSFB. The final grade of the project (Standards 11) is obtained from the partial grades obtained from the different activities (45%) and the final grade from the show case (20%). The remaining 35% corresponds to exams assessing theoretical concepts conducted throughout the course. A specific example is presented, addressing the design and construction of a vehicle powered by hydrogen.

Table 9. Application of the BSQE methodology.

|          |                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Conceive | Students are organized into teams. Each one is assigned a tutor from among of the degree professors and a leader from the 4th-year students. The car must be based on ChemEcar rules (Chem-E-Car AIChE, 2023), adapted to the conditions of their knowledge level. And a kit with the base of the car is given to the students. The objective is that teams have to produce their own hydrogen to operate the vehicle. The process on which |
|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

|           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|           | <p>the overall API1 is developed is the production of the hydrogen thanks to an electrolysis of an electrochemical path.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Design    | <p>The team conduct a laboratory experiment, which is based on the research done of the relationship between the potential of an electrochemical cell and the working temperature. Apart, they have other laboratory sessions where they must achieve specific objectives. The first one is to practice with the proposed chemical method to produce hydrogen and its optimization. Once the chemical part is solved, the teams must be able to obtain hydrogen with the technical requirements to be able to operate the fuel cells, this means that must, at least, be hydrogen 95% in volume. So, they must be able to measure this concentration and design and build a method to achieve it. They have valves, tubes and other standard materials to do it, and the assistance of lab personnel.</p>  <p style="text-align: center;">Figure 9. Laboratory practices example.</p> |
| Implement | <p>Each team constructs a vehicle in accordance with the characteristics and requirements defined. They apply their hydrogen product in the small fuel cells cars that they have to build and operate from the delivered kit (Figure 7). Once the car moves, the teams calibrate it in order to perform the competition with the specified rules.</p> <p>They also approach and resolve a material balance. The evaluation of the activity considers the difficulty of the calculations involved, the solution chosen and phase balances that require the solution of systems of <math>n</math> equations with <math>n</math> unknowns. All activities are in accordance with the skills acquired in the subject of computing in process engineering (Standard 3).</p>  <p style="text-align: center;">Figure 10. Final prototype of the ChemEcar.</p>                              |
| Operate   | <p>Finally, they elaborate a poster (size A0) and a video (maximum 2 minutes) describing the API1, with emphasis on the design of the vehicle.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

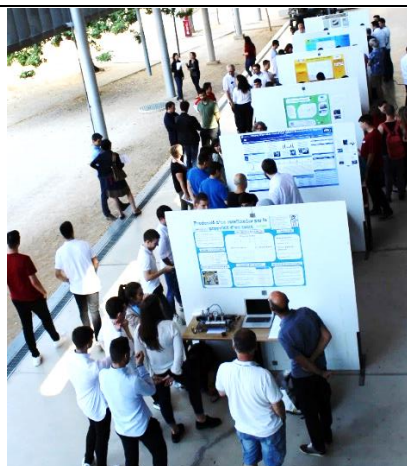


Figure 11. Exhibition of the poster and video.

Figure 8 shows the final showcase where the groups present their poster and videos. At the end of the presentation, a competition takes place among the cars of each group. The competition is based on a playoff scheme similar to the final ChemEcar event (Chem-E-Car AIChE, 2023). Throughout the various phases, each car must reach different distances. Figure 9 illustrates the final competition.



Figure 12. Competitive car race showcase.

## RESULTS

The evaluation of these projects aims to assess the positive impact they have on students' learning experience and the quality of their execution. In this case, the assessment was conducted through a survey, designed to guide questions towards the principles of the CDIO syllabus (Malmqvist et al., 2022). Table 4 shows the 15 questionnaire items administered to students and their relationship with the competencies outlined in the CDIO syllabus. The statements allow students to express their level of agreement, using a scale from 1 to 10, where 1 indicates total disagreement and 10 indicates total agreement.

Table 10. Relationship between the statements and the CDIO syllabus.

| CDIO Syllabus 3.0                      | Statements                                                                                                           |
|----------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| 1. Fundamental knowledge and reasoning | S1- This project allowed me to put into practice the concepts learned in classes of this or other subjects.          |
|                                        | S2- I had to search and analyze information from different sources to understand the problem and propose a solution. |

|                                                                                                                                             |                                                                                                                                       |
|---------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| 2. Personal and professional skills and attributes                                                                                          | S3- Working on this project helped me identify the strengths and weaknesses in my technical knowledge.                                |
|                                                                                                                                             | S4- I had to manage time and resources effectively to achieve the objectives of the activity.                                         |
| 3. Interpersonal skills: collaboration, teamwork and communication                                                                          | S5- Defining the roles and responsibilities of team members was essential for the development of the project.                         |
|                                                                                                                                             | S6- In this project, I have realized the importance of knowing how to work in a team.                                                 |
|                                                                                                                                             | S7- Through this project, I was able to enhance my oral and written communication skills.                                             |
| 4. Conceiving, designing, implementing and operating systems in the enterprise, societal and environmental context – the innovation process | S8- The fact that the project had a real-life statement helped me realize the impact of my discipline on society and the environment. |
|                                                                                                                                             | S9- The activities prior to the project helped me acquire the knowledge necessary for carrying out the work.                          |
|                                                                                                                                             | S10- The project's design process allowed me to enhance the prototypes from a functional perspective.                                 |
|                                                                                                                                             | S11- I find it satisfying to see how my idea transforms into a design and, ultimately, into a functional prototype.                   |
| <b>Student satisfaction statements</b>                                                                                                      |                                                                                                                                       |
| S12- I tried to participate in this project to the best of my abilities.                                                                    |                                                                                                                                       |
| S13- I am confident in applying the skills I have acquired in the future.                                                                   |                                                                                                                                       |
| S14- I believe the preparation time for each delivery is sufficient.                                                                        |                                                                                                                                       |
| S15- I think the assessment methods (presentation, report writing, prototype creation, etc.) are appropriate.                               |                                                                                                                                       |

The 201 students enrolled on course 2022-23 had an average age of 18 years, with 26% of women. The results shown on Figure 10 are made with the students answers and since the survey was optional, 52 students answered the questionnaire. The results from the sample of 52 answers from a population size of 201 is a low number of responses, but they are statistically significant at a 90% confidence level, with a margin of error of 10%. The proportion of answers of women was similar as the proportion of women enrolled. These responses measure student satisfaction and contribute to the continuous improvement of project quality, enhancing the overall educational experience for everyone involved.

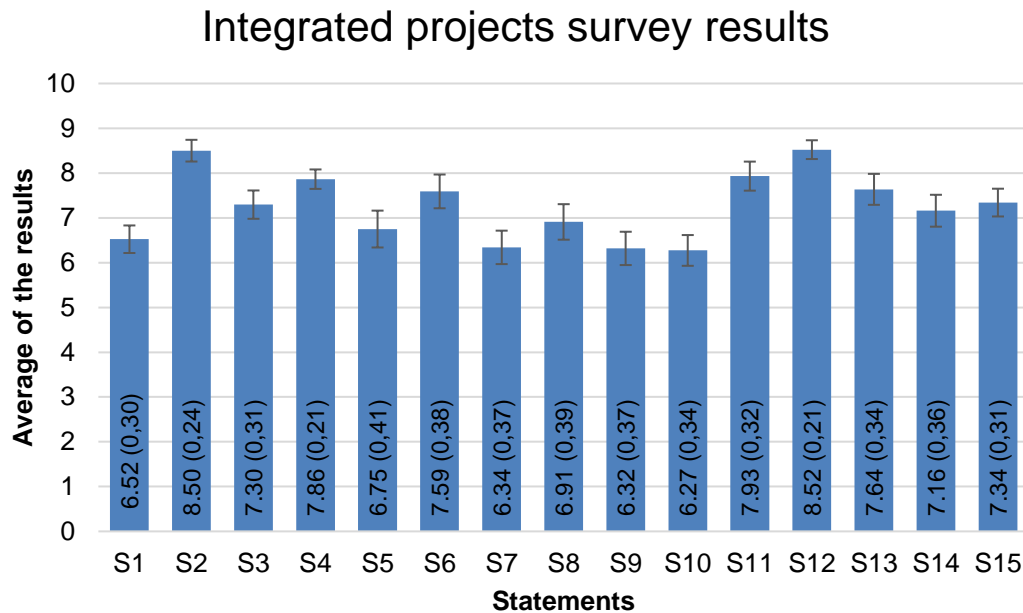


Figure 13. Integrated projects survey results with average of every statement and its standard error (see values between parentheses).

At the end of the assessment, there was an open question where students shared their impressions and experiences, as well as provided recommendations and suggestions for potential improvements. We show an excerpt of the students' opinions regarding the experience: STUDENT A: "I find it very interesting to see how a group of first-year students can undertake such a demanding project." STUDENT B: "It's a very good project for the future employment, but many times, the assignments pile up during the final exams period" STUDENT C: "This project is well implemented and helps understand how engineering projects impact the real world." STUDENT D: "A possible improvement would be to carry out the conceive activities before starting the task that requires this knowledge. Personally, I felt overwhelmed by receiving a lot of information at once. Nevertheless, I consider the sessions necessary and well-planned in terms of content."

Other results and a proof of the motivation that these projects make excel the students is that, in 2017, one of the cars powered by a chemical process won an award in a global competition (URV team, 2017). Additionally, the university is renowned for these public competitions among first-year students. An example is this video (Universitat Rovira i Virgili, 2022) summarizing the achievements during the year 2022, specifically the mechanical engineering project.

## CONCLUSIONS

The integrated project results reflect a generally positive evaluation of the CDIO educational program's impact on the students' learning experience, which demonstrates the benefits of the integration of the CDIO syllabus into their educational experience. The survey results suggest that the program has been particularly effective in areas related to teamwork and communication (Statements S5 to S7), as well as the practical application of learned concepts (Statements S1, S8, S10, S11). This aligns with the principles of the CDIO initiative, which

seeks to combine theory with practical application, thereby enhancing the development of both technical and interpersonal skills. However, opportunities for improvement have been identified through student feedback. For instance, one student suggested spacing out pre-work activities to prevent information overload, which could improve knowledge retention and practical application. Another student pointed out the challenge of balancing project workload with final exam preparation, suggesting the need for better scheduling or additional support during exam periods. So, improving these aspects could contribute to a more effective and satisfying educational journey for all program participants.

The limitations of this work are related to the specific disciplines studied, and our findings may not be directly applicable to other engineering disciplines or educational contexts. Another limitation is that while this methodology has been applied for more than 10 years, the assessment through student surveys has only been implemented in the 2022-23 academic year and the survey was completed by 26% of the enrolled students. Results from surveys conducted over multiple years would help to confirm the findings.

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# **CDIO-INFUSED SERVICE LEARNING: MANUFACTURING PROJECTS FOR SOCIETAL IMPACT THROUGH COLLABORATIVE PROJECTS**

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## **ABSTRACT**

This work explores the integration of the CDIO framework within a third-year Mechanical Engineering course focused on manufacturing, with a focus on service learning. University students collaborate with peers from vocational schools to optimize manufacturing processes and materials selection, delivering impactful projects to social entities. The service learning component enhances the practical application of CDIO principles, emphasizing the societal impact of engineering solutions. The third-year Mechanical Engineering curriculum at Universitat Rovira Virgili introduces a distinctive approach by integrating CDIO principles with service learning. The projects, designed with a focus on service learning, culminate in the delivery of tangible solutions to social entities. In this combination of CDIO principles and service learning, the third-year Mechanical Engineering course becomes a crucible for transformative education. Graduates emerge not only with technical proficiency but with a heightened sense of social responsibility, teamwork, and adaptability, which are essential attributes for success in engineering with a societal impact. The vocational school students have the first contact with the university and motivate them to excel in the manufacture of the projects that are delivered to social entities. The projects stand as tangible proof of the CDIO-infused service learning journey, illustrating the potential of engineering to create positive change in communities.

## **KEYWORDS**

Service Learning, Vocational School, Mechanical Engineering, Manufacturing; Standards: 1, 3, 6, 8, 11.

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## INTRODUCTION

The integration of service learning in the project aligns with the CDIO initiative by providing students with a holistic engineering education. Service-learning is a pedagogical approach that has gained prominence in various academic disciplines and institutions (Salam et al., 2019). It entails the integration of academic coursework with community service, emphasizing key elements such as reciprocity, reflection, and addressing community-expressed needs. Compared to other interactive and experiential-based learning approaches, such as project-based learning or problem-based learning, service learning stands out for its direct engagement with community issues and its integration of service as a core component of the educational experience. While project-based learning often revolves around completing a project to demonstrate mastery of academic content, and problem-based learning centers on solving complex problems, service learning goes a step further by emphasizing the importance of social responsibility and civic engagement. This concept provides students with the opportunity to apply their knowledge to real-world social issues (Tsang et al., 2001). In doing so, students acquire crucial skills, such as the ability to work in multidisciplinary teams, understand ethical and professional responsibilities, communicate effectively, and have a comprehensive education that enables them to grasp the impact of engineering solutions on a global and societal level (J. Duffy et al., 2000). CDIO principles emphasize the importance of conceiving, designing, implementing, and operating real-world systems, and the service-learning aspect of this project allows students to apply these principles to address community needs (Cea et al., 2014; Díaz Lantada et al., 2019). Furthermore, the students, in this case, can choose the project topic, so this presents an opportunity to analyze and identify ways they can create solutions that benefit the community.

This project not only stands out for the implementation of service learning but is also made possible through collaboration with several vocational training schools. The university handles the project's conceptualization, while the construction phase takes place in the vocational training school. Nevertheless, throughout each phase, both entities remain in contact. During the construction phase, the vocational training school assists the university students in ensuring the prototype is feasible for construction. Similarly, during the construction phase, vocational training schools maintain communication with the university to address any queries regarding the construction procedures. Every project is assigned to a specific training vocational school, this involves adapting the project to the machinery available in that place. This approach not only enhances pedagogy but also facilitates the coordinated construction of a technical environment, fostering the exchange of facilities and knowledge. Students are challenged to adapt and closely collaborate with the vocational school, providing a multidisciplinary approach to the project and significantly contributes to higher quality in the execution of future projects (Zeman & Hrad, 2014). Upon completing the project, students have gone through the various phases involved in a project. Furthermore, as it involves a final physical construction, students can appreciate how their prototype benefits society.

The emphasis on multidisciplinary teamwork, ethical responsibility, and effective communication, as highlighted by CDIO, is evident in the collaborative nature of the project involving both university and vocational school students (Thomson, 2019). The students' active involvement in selecting and analysing real-world problems mirrors CDIO's focus on preparing graduates to engage with contemporary issues and work on solutions that have a positive impact on society (Basso et al., 2020). The paper's aim is to explore the integration of SL and CDIO frameworks in engineering education to enhance the societal impact of engineering solutions and how the students perceive the benefits of this integration in their academic training and the collaboration with external organizations. The pedagogical approach based

on CDIO allows to improve the connection between the university and vocational training schools so that university students can perform tasks very similar to real ones they will encounter when working, since the designs created are validated for manufacturing, unlike other subjects where tasks are not validated in a real environment.

This project is part of the subject "Manufacturing" of 3 ECTS, but it is also related with the subject "Manufacturing Laboratory" of 3 ECTS, which help students to better understand the limitations of the manufacturing processes for the projects. These subjects are carried out during the third academic year of mechanical engineering degree at Universitat Rovira i Virgili, Catalonia, Spain. It's worth noting that these subjects integrate both theoretical content and the practical execution of the project in a coordinated manner. The project has a 30% weight in the subject assessment and specific sessions (minimum of 3) to review and support the projects are carried out. This project has been developed since the academic year 2017-2018, and this proceeding examines the impact and evaluation that students have had since that year.

## **METHODOLOGY**

The two subjects that contribute to this project are distributed over a term of 15 weeks (7 h/week), with 4 hours allocated for theoretical lectures and 3 hours for laboratory activities. In the theoretical developments, all students are in the same group in the lecture room with the professor, whilst in the laboratory activities, students are divided into smaller groups. The theoretical presentations explain the key concepts for manufacturing pieces such as: manufacturing processes for parts, geometric verification of parts, treatment of tolerances and fits, identifying machines, tools, fixtures, and elements; calculation issues related to different forming processes, programming in numerical control and welding processes. At the same time, in the laboratory, practical exercises related to each concept explained in the theoretical part are carried out. This allows students to apply theory in practical laboratory scenarios, thereby promoting active learning (Standard 8).

The project grade accounts for 30% of the total grade in the Manufacturing subject. This score is determined using a rubric that assesses various aspects of the written work (Standard 11). The rubric primarily focuses on the quality of the project's content, as well as aspects such as research, organization, references, among others.

So, the subjects provide all the necessary concepts to implement the main project, which involves the conception, design, implementation, and operation (CDIO) of a device to address a societal need. The project evolution can be broken down by following the principles of the CDIO philosophy (Goh et al., 2023). The following diagram illustrates how each of these principles can be linked to different project phases.

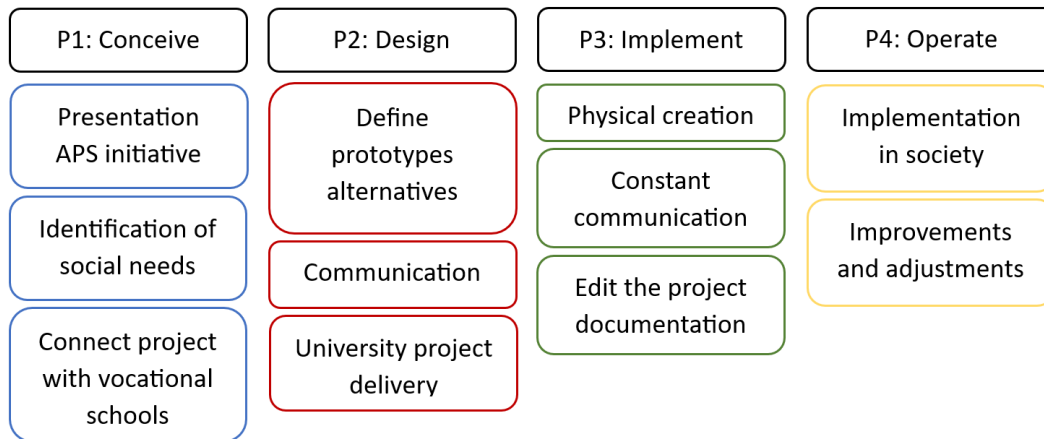


Figure 14. CDIO principles in the execution phases.

During the first phase of the project (conceive), the concept of Service-Learning (SL) is introduced. The premise is to develop a project with the goal of building something that contributes significantly to society and can be manufactured by a vocational training school. Students are assigned the task of analyzing societal needs to identify an issue that can be resolved collaboratively (Standard 1). Given the scale of the project, groups of 7-8 students are formed. During the initial weeks, groups are tasked with determining the theme of their project and appointing a representative, crucial for efficient organization due to the project's magnitude. Once the theme is chosen, the representative presents it in a class forum, providing a brief summary of the project. At this stage, the teacher reviews the proposal and gives approval once the project is correctly defined and could be manufactured with the skills and equipment from vocational schools. Subsequently, the teacher associates each project with a specific vocational training school, considering the various machinery and resources available at each school. The evaluation is based on the alignment of vocational school resources with the specific needs of each project. With the teacher's approval, students can start the project execution.

The second phase, led by university students, focuses on the design. Each group develops various prototypes that are subsequently sent to the corresponding vocational school. Therefore, an evaluation is conducted to facilitate the selection of the optimal prototype for manufacturing. Following this choice, the group proceeds to address all aspects of the project. The project involves the creation of a three-dimensional design for the graphic representation of the equipment. This model serves as the foundation for the development of manufacturing drawings. Each group adapts the manufacturing methods of the components to the capabilities of the machines available at their vocational training school. To guide the manufacturing process, specific details are provided, such as the initial material, manufacturing drawing, and the manufacturing procedure guide. Additionally, manufacturing time calculations are carried out to apply the concepts taught during the course (Standard 3). Once this part is completed, university group present the memory of the project and a video presentation.

Vocational school starts the implementation phase of the project. Initially, they conduct a comprehensive evaluation of the project, normalizing many of the components to optimize them for workshop manufacturing processes. During this stage, they make necessary adjustments, including redrawing certain aspects to align with the capabilities of their machinery (Standard 6), ensuring better applicability to the workshop fabrication process. Throughout this implementation process, there is constant communication established between vocational school students and university students. This ongoing collaboration allows

for the exchange of recommendations and the prompt resolution of any challenges that may arise. As vocational school students progressively construct the physical prototype, university students remain actively, they continuously edit the project documentation, marking and documenting the changes made during the implementation phase. This iterative feedback loop ensures that the evolving needs and adaptations on the vocational training school side are accurately reflected in the project documentation, promoting a seamless integration of efforts between the two educational institutions.

During the final phase of the project, the Operate stage, the constructed prototype becomes a tangible reality. The prototype is tested in the specific societal context it aims to assist. Both the university and vocational school components actively participate in this phase to ensure the functionality of the machine and address any technical issues that may arise. This operational testing phase serves as a crucial step to validate the practical application of the project and its potential impact on society. It provides an opportunity to identify and resolve any unforeseen challenges or errors that may have emerged during the construction and implementation stages. In cases where improvements or refinements are identified during the operational phase, these insights are documented. The findings, along with suggested enhancements, are then presented as a project for the following academic year. This creates a dynamic and multidisciplinary initiative, fostering collaboration among students within the same degree or training cycle. The continuous cycle of improvement ensures that each iteration of the project builds upon the experiences and lessons learned from the previous one, contributing to an ongoing and evolving educational endeavor.

A specific example is presented, addressing the design and construction of an innovative machine designed for the collection of microplastics—an environmentally pressing issue. Throughout the detailed phases in the methodology, from the formalization of the project to the final operation, this example serves as a practical illustration of how theory translates into a concrete solution with a direct impact on society.

Table 11. Specific example of the methodology.

|              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| P1: Conceive | <p>The group decides to develop a machine for filtering microplastics of the sand. The decision to undertake this project is because of an issue on the beaches of Tarragona related to the abundance of microplastics, specifically plastic pellets. Although the beaches are cleaned with large machines that collect waste, this type of plastic is too small to be filtered by this equipment. Therefore, the removal of these plastics is done manually with strainer. The goal of the machine is to streamline and automate the process of filtering plastic pellets, providing a more effective and efficient solution.</p> <p>After the topic was chosen, the summary was posted on the class forum, and the proposal was accepted by the teacher. To carry out the project, a collaboration was established with the "El Palau" vocational training school, considering that it had all the necessary tools to implement this machine.</p> |
| P2: Design   | <p>The design phase begins, and various prototypes are proposed to the vocational school to assess their functionality and construction. Figure 2 shows different prototypes.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

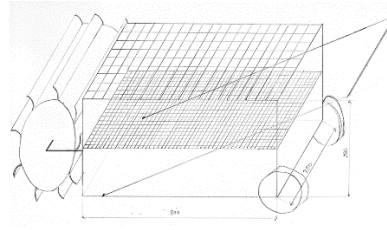
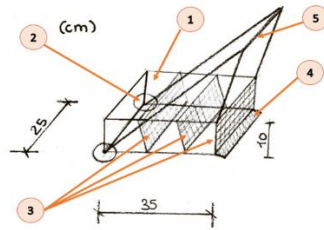


Figure 15. Prototypes of the machine for filtering microplastics

Once they have the final prototype, students begin the part design and 3D construction phase.

For each component, it was developed the manufacturing drawing, identified the required machining equipment, and created the process sheets.

| Operation Nº | Equipment | Sketch | Machined length (mm) | Feed (mm) | Feed rate (mm/min) | RPM  | Vc (m/min) | Time (min) | Observations                                                |
|--------------|-----------|--------|----------------------|-----------|--------------------|------|------------|------------|-------------------------------------------------------------|
| 11           | Lathe     |        | 30                   | 2         | 0,2                | 1400 | 80         | 0,22       | Rough-turn (for attaching the foot support with bearing)    |
| 12           | Lathe     |        | 30                   | 1         | 0,1                | 1900 | 96         | 0,16       | Finished-turn (for attaching the foot support with bearing) |
| 13           | Lathe     |        | 64                   | 1         | 0,2                | 1300 | 80         | 0,25       | Rough-turn (for setting the grindstone)                     |

Figure 16. Example and corrections on a process sheet.

Figure 3 illustrates an example of the process sheets for one of the pieces, with the vocational school's correction indicating that step number 13 is not necessary.

P3: Implement

Once the prototype is available, the vocational training school initiates the construction phase using the lathe, milling machine, and band saw. Students possess the necessary skills to carry out these operations and adjusted the drawings (Figure 4) for a more efficient construction. Throughout the process, unforeseen challenges emerged, leading to modifications in various parts. University and vocational training students work together to solve the problems.



Figure 17. Drawing adjustment.

P4: Operate

Once the machine is constructed (Figure 5), it was taken to the beach "Platja Llarga", in Tarragona to verify its functionality. Different

students with a representative from the university group and another from the social entity that promoted the prototype went to the location to implement the machine. Local television covered the trial, and this video (CCMA, 2023) showcases the events that took place on that day. Multiple news articles (Riu, N., 2023) (Diari de Tarragona, 2022) have been published regarding the implementation of this machine.

During the beach trial, some deficiencies in the machine were identified. For instance, it only filtered dry sand, not wet sand; the wheels did not rotate or move correctly in the sand, and only a small amount of sand was filtered at a time, among other observations. All aspects requiring improvement were compiled and presented this year as a Service-Learning project to students currently enrolled in the course.



Figure 18. Final prototype built

Below, additional examples of projects are presented:



Figure 6. Knee rehabilitation equipment

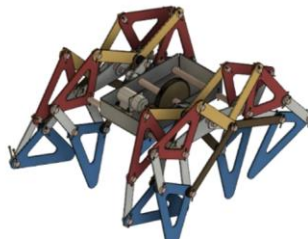


Figure 7. Walking robot.

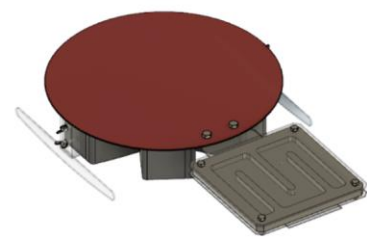


Figure 8. Bosu for people with disabilities



## RESULTS

To carry out an assessment of the project, a survey was implemented with the aim of gathering students' perceptions. The three main objectives of the survey were as follows:

- Understand students' perception of the tasks carried out.
- Understand students' perception of their relationship with the faculty and the vocational school.
- Understand students' overall assessment of the Service-Learning experience (SL).

The survey comprised six questions, where participants were required to assign scores ranging from 1 to 10, with 1 indicating completely disagree and 10 indicating completely agree. Additionally, a general assessment question was included, rated on a scale from 1 to 10. Below, detailed results derived from this assessment since 2017 are presented in Figure 9, Table 2 and 3.

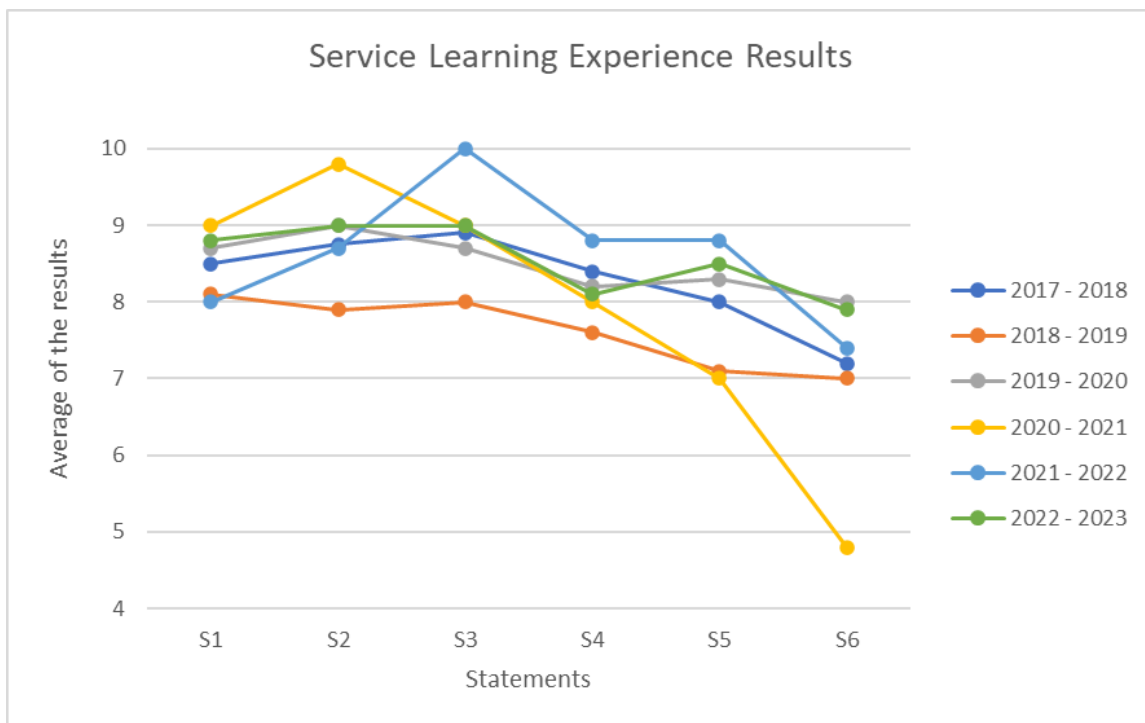


Figure 19. Results of the survey since 2017.

Where:

Table 12. Survey statements.

|    |                                                                                                     |
|----|-----------------------------------------------------------------------------------------------------|
| S1 | I have carried out the proposed tasks.                                                              |
| S2 | The performed tasks have had a direct relationship with my academic training.                       |
| S3 | I have put into practice the knowledge acquired previously at the University.                       |
| S4 | The SL experience has been a formative complement.                                                  |
| S5 | I have received information, guidance, and support from the university faculty.                     |
| S6 | I have received supervision and support from the external organization in the development of tasks. |

Finally, table 3 shows the average of the general assessment question with its standard deviation values:

Table 13. Results of the general qualification.

| Year        | Average general qualification | Standard deviation |
|-------------|-------------------------------|--------------------|
| 2017 - 2018 | 7,51                          | 1,58               |
| 2018 - 2019 | 7                             | 2,58               |
| 2019 - 2020 | 7,86                          | 2,57               |
| 2020 - 2021 | 7,67                          | 2,07               |
| 2021 - 2022 | 7,5                           | 0,71               |
| 2022 - 2023 | 7,85                          | 0,99               |

Given that the implementation of Service Learning in the project is a new concept, students conducted a reflection on SL in which they shared their impressions and experiences, as well as provided recommendations and suggestions for potential improvements. Below is shown an excerpt of the students' opinion regarding the experience:

GROUP A: "To conclude, we will say that we feel very proud to have carried out this great work. We have worked hard to achieve a good final grade on the project, but beyond that, we feel satisfied with the service we have provided to the community. We hope that one day the construction of this saw at El Palau vocational school becomes a reality, and above all, that it proves to be truly useful for those who will have to use it."

GROUP B: "This experience has led the members of the group to grow both professionally and personally. It has opened many doors by demonstrating that achieving a successful project not only allows for manufacturing, but the simple act of social commitment is a significant step towards achieving socially responsible professional development."

GRUP C: "The time required to complete the projects I consider fair, but I believe that to produce a high-quality project, perhaps a longer timeframe should be included. It could be done over two semesters. I find it to be an interesting project as it simulates the actual work of an engineer."

GRUP D: "Up until now, many of the assignments we have undertaken for university or other studies had little utility for society; they were more about earning a grade than making a meaningful impact. That's why we believe Service-Learning (APS) is a good way to promote

education, as it ensures that the work being done will have a lasting impact and contribute to helping someone.”

GROUP E: "... we have gained insight into all the machines and equipment in the vocational school's facilities. This allows us to carry out and plan machining processes that are suitable for the available resources, ensuring the proper manufacturing of the projects. Having a dedicated section on Moodle (the URV's e-Learning platform) with subsections for each working group has been an innovative and effective idea. It has enhanced communication among ourselves and the students at the vocational school. However, we acknowledge that we could have utilized this efficient APS system more effectively. Looking ahead to future projects in our program, we will undoubtedly take this into account and leverage it more extensively."

## CONCLUSIONS

The analysis of the service learning experience (survey data and student feedback) indicates that students have positively rated their experiences with SL projects. The survey results show a general trend of students agreeing that they have carried out the proposed tasks (S1), found a direct relationship between these tasks and their academic training (S2), applied knowledge acquired from the university (S3), and viewed the SL experience as a formative complement (S4). However, it is important to highlight that the scores for faculty support (S5) and external organization support (S6) have consistently been the lowest throughout the years. Highlighting the year 2020-2021, this result could be due to the COVID-19 pandemic, which affected communication between teams and the external organization.

This less favorable trend regarding communication between students and entities has been a constant focus of improvement each year. To enhance this communication some strategies have been implemented, such as facilitating open and structured feedback channels, and encouraging active participation from both parties in project planning and execution. These measures would not only strengthen collaboration but also contribute to a more efficient and enriching process for all parties involved.

The average general qualification has fluctuated over the years, with a peak in 2019 – 2020. The overall trend indicates a generally positive performance, with the majority of years reflecting averages above 7. This suggests a consistent level of academic achievement. However, it's noteworthy that the participation of students in the satisfaction survey is low. To improve participation, we try to implement strategies such as incentivizing responses emphasizing the significance of feedback in enhancing educational experiences. Enhancing the survey administration process can contribute to a more accurate understanding of student satisfaction and facilitate targeted improvements in the academic environment.

The qualitative feedback from the groups (A, B, C, and D) reveals that students have found value in the SL projects beyond academic achievement, expressing pride in their community service, personal and professional growth, the utility of their work for society, and a desire to see their projects implemented and used in the real world. In conclusion, students' reflections reveal a deeper appreciation for the practical application of their studies, the social impact of their work, and the collaborative process of learning. It will be beneficial for the university to continue fostering these opportunities and perhaps focus on enhancing the aspects of communication and project management to further improve the student experience.

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# TRANSFORMING ENGINEERING LEARNING TOWARDS SUSTAINABLE DEVELOPMENT

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## ABSTRACT

Sustainable development has emerged as a global priority in response to the challenges posed by environmental degradation, social inequality, and economic instability. Engineering plays a crucial role in addressing these challenges, and engineering education is pivotal in creating a sustainable future. To effectively address these challenges, it is imperative to integrate its principles into the engineering curriculum. The incorporation of the United Nations Sustainable Development Goals (UN SDGs) into specific courses is a commendable start. However, Sustainable Development Goals (SDGs) are not abstract concepts but practical challenges that require real-world solutions. To apply sustainable principles across various engineering contexts, from design and implementation to operation and maintenance, we emphasize the need for a more comprehensive and transformative integration. To adequately prepare engineering students to contribute to the fulfillment of these goals, we propose, in this paper, an approach that aligns with the CDIO framework's principles throughout the engineering learning process. This work is a direct outcome of an initiative at ESPRIT School of Engineering. The teaching and learning process at Esprit is based on active pedagogy and openness to the professional environment, thus fostering the training of operational engineers. We present the process of transforming engineering learning towards sustainable development and identifies key initiatives that have been implemented to achieve this transformation at multiple levels and across diverse disciplines. As a result, a new generation of engineers dedicated to creating a more sustainable world learns how to conceive projects that address environmental, social, and economic issues. The paper explores the benefits of these approaches and the positive impact of these initiatives on student learning outcomes and faculty development.

## KEYWORDS

Engineering Learning, Sustainable Development Goals Implementation, Framework, Standards 2,3,7, 9

## INTRODUCTION

The structure of society is facing considerable challenges linked to social injustice, environmental degradation, gender inequality, inclusive education, and sustainable development. In this respect, higher education institutions play the role of agents of change from a sustainability perspective and have an obligation to act. They are establishing new cross-sectoral collaborations, securing new sources of funding, and equipping students, faculty, and staff with skills to inspire and empower them to implement sustainable development goals in their daily lives. To design and implement sustainable solutions, future engineers should be equipped with knowledge, skills, and values. Indeed, engineering schools require to incorporate sustainability principles into engineering curricula.

This work discusses a case of Esprit School of engineering. Initially, a new reference framework, considering the specific features of Esprit School of Engineering training, is presented. This framework integrates both the Green Reference Framework and the Conférence des Grandes Ecoles (CGE) Framework, incorporating the latter's five cross-cutting competencies. Then, we propose an approach that integrates SDGs from the learning outcomes to the curriculum and various integrated learning experiences, as well as faculty professional development. The integration of sustainable development objectives has been studied, presenting various aspects of integration, development, and the benefits within this academic context.

This paper is structured as follows. Section 2 reviews related work on the integration sustainability concepts. Section 3 describes the establishment of the ESPRIT reference framework. Section 4 offers insights into the process of transforming engineering learning towards sustainable development. Section 5 highlights the impact of this process on students and faculty members. The last section is devoted to providing a conclusion that encapsulates the details outlined in the paper.

## RELATED WORK

Various international initiatives are actively promoting the integration of SDGs within university curricula. This section delves into the approaches employed for incorporating sustainability concepts into engineering education and provides illustrative examples. These initiatives primarily concentrate on enhancing awareness among students and university staff regarding sustainability issues. and cultivate collaborations with businesses and civil society organizations. The engagement of higher education institutions (HEIs) with each Sustainable Development Goal is pivotal for disseminating information and mobilizing individuals through educational strategies and environmentally conscious projects.

For instance, Babes-Bolyai University (BBU) (Zanellato & Tiron-Tudor, 2021), offering study programs in multiple languages, has strategically positioned itself in international rankings related to sustainable development. An investigation was conducted on the official websites of faculties and research centers involved in sustainable development activities. It revealed initiatives such as new educational programs, collaboration with research groups, and articles published on various SDG-related issues. Through its strategic plans and follow-up actions, BBU has achieved an advanced international ranking, showcasing its commitment to reducing ecological footprints and aligning with national, European, and international sustainable development regulations.



Another exemplary model comes from the University of Seville and the University of Extremadura, Badajoz in Spain (Setó-Pamies & Papaoikonomou, 2020), illustrating successful incorporation of ethics, corporate social responsibility, and sustainable development into management education and engineering design departments. Their study emphasizes the concrete perspective management education contributes to SDGs through education, research, innovation, and leadership. Practical implications drawn from stakeholder data include the need for specific training on SDGs for students, contextualized within education for sustainable human development, and the development of cross-cutting skills across the curriculum.

Cheah (2021) presented a comprehensive review of the integration of SDGs in engineering curriculum, particularly in the field of chemical engineering. By placing a stronger emphasis on empowering students, the goal is to equip them for shaping their perspectives on the complex nature of sustainability issues. This involves considering the diverse and sometimes conflicting viewpoints of various stakeholders. An evolving approach in transformative learning centers around sustainability as a discourse.

## **ESTABLISHMENT OF ESPRIT REFERENCE FRAMEWORK**

### ***ESPRIT presentation***

The School of Engineering being discussed is a private higher education institution that was founded in 2003. It employs around 400 teachers and has a student population of over 12,000. The four core departments are Civil Engineering, Electromechanical Engineering, Information Technology, and Telecommunications. Many recognitions demonstrate the world-class pedagogy created by the school faculty which empowers students to take on more responsibility in the learning process. The school also provides various academic and non-academic facilities and services to students. To address sustainability challenges and transform engineering learning towards sustainable development, ESPRIT establishes a new reference framework and adopt an approach that integrates SDGs from the learning outcomes to the curriculum and various integrated learning experiences, as well as faculty professional development.

### ***Existing frameworks***

The labeling framework, known as the "Sustainable Development and Corporate Social Responsibility Label" (DD&RS), for higher education institutions was introduced in 2015. It is based on a common national set of standards dating back to 2009, in accordance with Article 55 of the Grenelle 1 environmental law. This framework is the result of collaborative efforts involving a dozen universities and Grandes Écoles, the Conference of Grandes Écoles (CGE), the Conference of University Presidents (CPU), the Ministry of Sustainable Development, the Ministry of Higher Education, and the "Réseau des étudiants pour une société écologique et solidaire (RESES)." It allows higher education and research institutions to receive national and international recognition for their sustainable development and corporate social responsibility initiatives. Additionally, it provides institutions with the opportunity to enhance their capabilities within a group of participating establishments by engaging in the labeling committee and auditing candidate institutions.

### ***ESPRIT Framework***

The steering committee at ESPRIT has taken the initiative to formulate the ESPRIT SDG Framework by aligning and intersecting two existing frameworks, considering the unique features of our school's training programs. This process involves a meticulous matrix intersection, placing a strong emphasis on aligning sustainable development skills, engineering program objectives, and the SDGs. This strategic approach ensures a systematic and consistent integration of sustainability principles throughout our educational curriculum (UN DESA, 2022).

The Conference of University Presidents framework, which encompasses five axes including Teaching and Research & Innovation, was thoroughly examined and addressed by the committee. Additionally, the second CPU-CGE framework, based on five competencies (foresight, responsibility and ethics, collectivity, change, and systemic), played a significant role in shaping the competency matrix. Notably, the development process underscored the importance of CDIO skills, especially in projects, practical work, and active pedagogy (Porter & Kramer, 2006).

The overarching goal of the Esprit SDG&R Framework is based on the integration of SDGs into education while considering the specificities of our school's curriculum. This framework is structured around two competency families: 'Learning to Apply Knowledge and SDG Skills' and 'Supporting and Recognizing Student Initiatives in SDG Projects.' Following a comprehensive reflection and clarification of competencies and learning situations associated with specific SDGs, each faculty member actively contributed by proposing approaches and suggestions to enhance the integration of sustainability issues into their respective modules/courses. This collaborative effort included considerations for workload and pedagogy details.

## **PROCESS OF TRANSFORMING ENGINEERING LEARNING TOWARDS SUSTAINABLE DEVELOPMENT**

ESPRIT has implemented a series of key initiatives fostering a holistic approach to effectively implement the SDG Framework. The initiatives outlined are categorized into three categories that capture their key objectives and focus areas. They highlight the comprehensive approach taken by ESPRIT, encompassing educational pedagogy, and learning integration, interdisciplinary collaboration and lifelong learning, and experiential learning with a focus on social responsibility. The framework was introduced in September 2022, and since then, it has involved all students, regardless of their specialization.

### ***Category 1: Educational Pedagogy and Learning Integration***

#### *Initiative 1: Implementation of Project-Based Learning*

The integration of sustainability involves rethinking traditional approaches to teaching and learning, as various skills are delivered through active learning. At ESPRIT, students are constantly engaged in role-playing scenarios, team-based activities, and problem-based learning projects to solve complex problems, often derived from real-life settings. ESPRIT engineering students learn how to analyze and solve complicated and complex problems, along with developing effective collaboration abilities within diverse teams.

Furthermore, PBL stands out as a pedagogical approach especially beneficial within the context of CDIO design-implement courses (Edström & Kolmos, 2012). This Approach provides students with opportunities to apply sustainable development principles during the

design of their projects. Students develop a comprehensive understanding of the social, environmental, and economic implications of their designs. It is also a pedagogical approach that fosters ethical decision-making and critical thinking skills necessary for sustainable engineering practice. To measure sustainability competencies, we have developed appropriate assessment tools and we have established continuous improvement through feedback.

Moreover, Project Fair which is a prominent end-of-year celebration, provides an exceptional platform for students to showcase their work through the organization of exhibition spaces, interact with a diverse audience, and receive feedback in a professional context. Indeed, the focus of Projects Fair edition 2023 was sustainable development and different topics with sustainability awareness were addressed.

*Initiative 2: Development of dedicated sustainability-focused courses*

Our programs offer dedicated sustainability-focused courses, ensuring that students develop a comprehensive understanding of sustainable development principles. Knowledge and skills necessary to address complex environmental, social, and economic challenges are also taken into consideration. These competencies are deemed essential within the Education for Sustainable Development domain for coping with the increasingly diverse and interconnected world and for contributing to sustainable development (Rosén et al, 2019). As a result, every student in every engineering specialty as shown in Table 1, is given a module providing an initial introduction to sustainable development. This module aims to introduce students to the connections between economic development and the significant environmental issues of today, as well as their social consequences.

Table 1. Dedicated sustainability-focused courses

| Course                                                        | Curriculum                                               | Knowledge and competencies                                                                                                                                                                                        |
|---------------------------------------------------------------|----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sustainable Development                                       | Information Technology and Telecommunication Engineering | Ensure the first immersion of students in sustainable development. Introduce the links between economic development and the major contemporary environmental issues and their social repercussions.               |
| Sustainable Development and Social Responsibility Initiatives | Electromechanical Engineering                            | Familiarize students with the concepts of sustainable development/Social Responsibility, the SDGs and the standards related to Health, Safety and Environment (HSE) as well as their applications in the company. |
| Urban planning and sustainable development project            | Civil Engineering                                        | Students imagine, propose solutions and innovate, always respecting the targets of sustainable development.                                                                                                       |

*Initiative 3: Incorporation of sustainability into core engineering courses*

In addition to the presence of dedicated courses, incorporating sustainability into core engineering courses plays a crucial role in ensuring the effectiveness of sustainable

engineering education at ESPRIT. The inclusion of sustainability concepts is ensured across various engineering disciplines. The learning outcomes are following suit, which involve changes to both the content of education and the methods of learning.

### **Category 2: Interdisciplinary Collaboration and Lifelong Learning**

#### *Initiative 4: Promotion of interdisciplinary collaboration*

Sustainable development challenges are inherently interdisciplinary and involve collaboration between professionals from diverse fields. To promote interdisciplinary approaches at ESPRIT, we encourage:

- joint research projects: ESPRIT supports faculty and students to engage in collaborative projects that address multifaceted issues and that draw on collective expertise from various disciplines. Additionally, the school seeks to stimulate research on sustainable development.
- interdisciplinary coursework: ESPRIT integrates interdisciplinary elements into its coursework, exposing students to a diverse spectrum of knowledge beyond their core disciplines. These skills are essential for navigating the complexities of real-world challenges.
- innovative initiatives: ESPRIT promotes project-based learning initiatives mirroring real-world scenarios that require collaboration among students with diverse academic backgrounds.

#### *Initiative 5: Promotion of lifelong learning*

Skilled engineers are crucial for achieving the 17 Sustainable Development Goals. However, innovative technologies, automation, demographic changes, and employment mobility require continuous reskilling for engineers. A commitment to lifelong learning can ensure that engineers remain well-equipped to contribute effectively to sustainable development. Our courses are regularly updated to reflect advancements in technology and industry trends. In addition, we collaborated with industry partners to ensure that our curricula and integrated projects are aligned with real-world challenges, facilitating practical, lifelong learning experiences. Our commitment to open accessibility and the diversity of online platforms ensures that anyone, anywhere, can benefit from our engineering courses. The variety of our platforms and approaches in the realm of open courses also contributes to lifelong learning in engineering.

### **Category 3: Practical Experiences and Societal Engagement**

#### *Initiative 6: Setup of internships*

In the pursuit of aligning engineering education with the principles of sustainable development, ESPRIT establishes four distinct internships. They are designed to provide students with a holistic understanding of the societal and human dimensions of engineering. The goal of the inaugural one "Human and Social Training Internship" is to foster a deep understanding of the human and social aspects of engineering. This internship engages students in activities that promote empathy, cultural awareness, and social responsibility.

In addition, the integration of SDGs into the evaluation of the end-of-studies internship contributes to raising students' awareness and measuring students' understanding of sustainability concepts.

#### *Initiative 7: Fostering club activities*

To cultivate a sustainable engineering mindset among students, fostering club activities is also considered an integral component. Our approach to nurturing club activities revolves around three key initiatives. We conducted a workshop to present the seventeen SDGs, Corporate Social Responsibility (CSR), and the significance of universities' contribution to the SDGs. Then, we integrated discussions on CSR emphasizing the role of businesses in creating a positive impact on society and the environment. Finally, we invited professionals and guest lecturers who are industry experts, and they provided practical insights into sustainable engineering practices.

#### *Initiative 8: Training and resources*

To align learning outcomes with real-world sustainability challenges, we engaged different stakeholders in engineering education. Partnerships and collaborations between academia, industry, and communities offer ESPRIT opportunities for internships, research projects, hands-on experiences, and cooperative education programs. In addition, the contribution of the industry into curriculum development ensures that graduates possess the skills required by the job market.

We provide advanced technologies like online learning platforms, simulation software, and virtual reality that offer new opportunities to enhance sustainable engineering education. They allow our students to explore and analyze complex systems and scenarios and supplement traditional classroom teaching.

On the other hand, curriculum changes are implemented systematically, with a focus on promoting and developing faculty members. To enhance understanding of sustainability concepts and methodologies, we have established a training program that includes workshops, conferences, and professional development opportunities. This program aims to enable the integration of sustainability principles into teaching practices.

Indeed, to incorporate the SDGs into engineering curricula, a training session was organized to assess the integration of SDGs into the training curriculum and evaluate their extent in the content. Following this, two workshops were conducted to demonstrate concrete methods of incorporating SDGs into the curriculum.

By the conclusion of the first workshop, all participants reached a consensus to include the SDGs in the summer internship and final project forms. Subsequently, by the end of the second workshop, the pertinent SDGs for each unit were identified, with ongoing efforts to integrate additional SDGs.

As an illustrative example, let's consider the implications of integrating SDGs into an English for Engineers course. Here are the proposed learning outcomes aligned with SDGs:

- Demonstrate critical thinking in collaborative environments through debates about the technologies in hand.
- Identify sustainable solutions to Sustainable Development issues and the different co-actors.

- Participate in the elaboration of projects related to social, cultural, and ecological entrepreneurship.
- Propose green innovations through the improvement, mitigation, adaptation, and transformation of existing solutions to sustainable development issues.
- Propose solutions to address issues related to uneven access to technologies.
- Engage with a group to implement permanent solutions to challenges faced in the world and the corporate world in specific.

Over the course of five years, more than 120 pedagogical supervisors have collaborated on nearly 200 units in the ESPRIT training program. The teachers participating in the workshop expressed strong interest in its content, activities, and outcomes, as well as in the training provided. Additionally, they expressed a desire for more time in the workshop, specifically requesting simulations of practical applications and a diverse array of case studies to represent various learning scenarios.

## **POSITIVE IMPACT OF OUR APPROACH**

The positive impact of the sustainable development approach adopted by ESPRIT in engineering education is reflected in its alignment with the CDIO standards (Crawley et al., 2014) and is delved into the tangible benefits on student learning outcomes.

### *Alignment with CDIO Standards*

The process of aligning engineering learning towards sustainable development at ESPRIT is designed to align to specific CDIO standards, namely Standards 2, 3, 7, and 9.

- Standard 2: ESPRIT's commitment to sustainable development is reflected in the learning outcomes of its engineering programs. The implementation of Project-Based Learning at ESPRIT ensures that students develop practical problem-solving skills in addition to theoretical concepts. Through hands-on projects, students are exposed to real-world scenarios where they initiate and design engineering solutions.
- Standard 3: The development of dedicated sustainability-focused courses and the incorporation of sustainability principles into core engineering courses align with CDIO Standard 3. ESPRIT's curriculum design reflects a commitment to providing effective engineering education, seamlessly weaving sustainability concepts throughout various engineering disciplines.
- Standard 7: The promotion of interdisciplinary collaboration and lifelong learning at ESPRIT is a direct manifestation of CDIO Standard 7. By encouraging joint research projects, interdisciplinary coursework, and innovative initiatives, ESPRIT prepares students to operate effectively in the dynamic and multidisciplinary engineering landscape. This aligns with the CDIO framework's focus on producing engineers capable of addressing multifaceted challenges. Furthermore, Internships and club activities at ESPRIT emphasize integrated learning experiences, including interactions with industry, societal engagement, and a deeper understanding of the societal and human dimensions of engineering.
- Standard 9: The improvement of faculty competence, collaborative efforts with industry partners, and a focus on professional development align with CDIO's Standard 9. This

alignment ensures that faculty members are well-equipped to integrate sustainability principles into teaching practices.

#### *Benefits on student learning outcomes*

The students have demonstrated a keen interest in sustainable development by incorporating the seventeen SDGs into all club activities. They actively utilize these goals to guide and achieve the objectives outlined in integrated projects. Out of 150 participating teams in project fair, 80 teams actively aligned their projects with the SDGs, showcasing their commitment to addressing global challenges. Among these, 80 projects underwent rigorous evaluation and selection by the DDRS jury. Additionally, 20 teams received visits, culminating in the recognition of the top three teams for their exceptional integration and contributions to the SDGs, as they were awarded prizes for their remarkable achievements.

Furthermore, this approach has yielded numerous benefits for student learning outcomes:

- enhance problem-solving skills and reinforcing academic concepts.
- foster a sense of responsibility and ethical decision-making in engineering practices.
- enhance critical thinking and prepare students for complex real-world challenges.
- ensure students remain relevant and adaptable throughout their careers.
- develop a holistic understanding of societal dimensions and enhance empathy and cultural awareness.
- develop a broader perspective on the role of engineers in addressing global challenges.

These initiatives not only enhance student learning outcomes by providing practical experiences and a comprehensive understanding of sustainability but also contribute to faculty development through engagement in collaborative projects, innovative teaching approaches, and a commitment to continuous learning.

## **CONCLUSION**

Transforming engineering learning towards sustainable development underscores the need for collective action from academia, industry, and stakeholders. The paper outlines a comprehensive and transformative framework adopted by ESPRIT to align engineering education with the principles of sustainable development. A set of initiatives is strategically deployed to effectively operationalize the ESPRIT framework. Informed by the latest findings and best practices in the field, this approach underscores the commitment to empower future engineers with the skills and values needed to contribute effectively to building a more sustainable and equitable future. The positive impact of ESPRIT's approach is evident in its alignment with CDIO standards. The benefits on student learning outcomes, ranging from enhanced problem-solving skills to a broader perspective on global challenges, highlight the success of ESPRIT's initiatives in preparing students for sustainable engineering practice. For continuous improvement, it is imperative to engage additional stakeholders, such as administrative staff, and strive for international certification.

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# **A DATA-DRIVEN FLIPPED LEARNING MODEL FOR ENHANCED STUDENT OUTCOMES**

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## **ABSTRACT**

This study investigates the integration of flipped classroom and learning analytics in the algorithm course through the Data-Driven Flipped Classroom model. This research arises from the backdrop of the traditional teaching model in algorithmic courses, where a one-size-fits-all method was applied. The challenges appear as instructors encountered difficulties managing a class with diverse levels of assimilation, limiting the attainment of learning outcomes. Recognizing the need for a more adaptive and personalized model, the study introduces the Data Driven Flipped classroom model. This model provides a dynamic and personalized learning experience. Experimental research with computer engineering first year students at ESPRIT School of Engineering demonstrates the proposed model's effectiveness. Using this model, new learning activities were designed where we strategically employed pre-class Quizzes, in-class interventions, and post-class discussion forums to guide students through exercises of varying difficulty levels. An experimental study was conducted to evaluate students' results and impressions. Survey results of the students (N=60) who participated in the experiment (experimental group) were compared to the results of the students from the control group (N=60). Significant improvements in students' problem-solving abilities, especially among those with lower starting assessments, demonstrate the model's potential to alter education.

## **KEYWORDS**

Learning Analytics, Data-Driven Flipped Learning, Algorithmic course, Standard 8.

## **INTRODUCTION**

In the world of education, finding new and creative ways to teach is crucial, especially when it comes to subjects as complex as algorithmic courses. Due to its intricacy and logical requirements, algorithm courses have long presented difficulties for instructors and students alike. It becomes essential to investigate and put into practise methods that not only improve learning but also encourage a deeper comprehension of algorithms, critical thinking, and problem-solving abilities in order to successfully navigate this educational landscape.

In recent years, the field of computer science education has witnessed a shift towards innovative teaching methodologies aimed at enhancing student outcomes and engagement. Ásrún & Hrafn's (2019) study emphasized student-centered learning, team-based activities, and the flipped classroom approach in programming education. The findings revealed that students actively engaged with online resources, valued communication with instructors and peers, and had a positive learning experience. The study underscored the role of visual aids like videos and the preference for online resources over traditional textbooks in teaching programming effectively.

On the other hand, Deachrut & Natha's (2019) emphasized the effectiveness of active learning strategies in improving student performance and understanding in computer programming courses. The research provided valuable insights for enhancing teaching methods and promoting student engagement in programming education. By implementing active learning approaches, the study aimed to optimize student learning experiences and outcomes, aligning with the evolving landscape of computer science education.

This study focuses on how to apply the data enabled flipped classroom, a current teaching technique designed to boost student performance and understanding in algorithmic courses. Data-Driven Flipped Learning (DDFL) takes the flipped classroom concept a step further by adopting learning analytics, which is the collecting and analysis of student data to inform and optimize education (Seng & Chuan, 2023). Within the flipped classroom framework, the use of data-enabled teaching and learning practices has enormous promise for not only increasing student outcomes but also customizing instruction to individual requirements.

Educators may better identify students' strengths and limitations by exploiting data-driven knowledge, tailoring exercises to different difficulty levels, and facilitating a more personalized learning experience. This combination of data and flipped learning has the potential to transform how algorithmic courses are taught, making education more effective, engaging, and responsive to learners' different needs.

This paper is organised as follows: the first section examines relevant literature on the use of flipped learning in algorithm courses, illuminating both its benefits and obstacles. Following that, emphasis will be placed on data-driven flipped learning and its underlying concepts. The next section explores into the methods used for the algorithm course, where student performance will be evaluated, as well as a thorough review of feedback from both students and instructors.

## **BACKGROUND AND RELATED WORK**

The flipped classroom, which has been recognised for its success in utilising technology in education (Chang & Hwang, 2018), is a potential technique for improving student's deep learning (Cui & Yu, 2019). This method emphasises higher-order thinking, resulting in a dynamic learning environment in which students may interact and grow at their own speed. Instead of teaching material, teachers in this paradigm act as facilitators, guiding and assisting students that take on more responsibility for their performance and learning activities.

### ***Flipped learning in algorithm courses***

When compared to the traditional paradigm, the flipped classroom has been demonstrated to be a more efficient means of teaching algorithms (Amira, T. 2019). For example, the material delivered in algorithm lectures is dense and difficult for many students to absorb at the speed

at which instructors give them (Garg, M. 2015). As a result, from time to time, the learner needs to pause and think on his own in order to keep up with the lecture, but in a traditional lecture, such a pause is impossible because the requirement differs from person to person. Furthermore, the information is sequential and strongly linked to each other, so if the learner's attention wanders for a second, he may miss much of the material from the rest of the lecture and simply waste time by attending the presentation. Both issues are addressed by video lectures, which are assigned to students as homework under the flipped classroom paradigm. The learner may view the video lesson at his own pace, pause it when he needs to think about a subject, or rewind it if he missed something.

A critical evaluation of the Flipped Classroom approach's effectiveness has been conducted, considering the perspectives of instructors and students. Using a flipped classroom approach has been associated with numerous benefits. It is thought to support critical thinking both inside and outside of the classroom (Herreid & Schiller, 2013) and enable active learning (Alhasani, 2015). In addition, it promotes regular feedback exchanges between students and instructors, increases student engagement, and permits a self-paced learning environment (Mok, 2014). On the other hand, several studies have demonstrated that certain students would find it difficult to control their flipped learning, which would cause them to show up to class unprepared to participate fully (Herreid & Schiller, 2013). Some students allegedly had trouble understanding the material from the online lectures, which suggests that early interventions are necessary to improve understanding (Bishop and Verleger, 2013).

### ***The data-driven flipped learning***

Data-driven flipped learning (DDFL) is a pedagogical approach that combines the flipped classroom model with learning analytics to personalize and optimize the learning experience. Understanding and improving learning experiences and the surroundings that support them is the main goal of learning analytics (Long & Siemens, 2011). The principal objective of learning analytics is to provide instructors with advanced techniques for gathering and analysing complicated data from interactions between instructors, students, and digital media (Mayer et al., 2009).

Learning Analytics and the Flipped Classroom paradigm together signal the beginning of highly adaptive learning environments. This integrative method fosters a learning environment where students feel comfortable participating in self-regulated learning and developing their metacognitive skills through thoughtful self-evaluation. For instructors, this combination appears as a dynamic feedback loop that seamlessly connects the virtual and traditional classroom spaces. Such iterative feedback allows instructors to assess and adjust to students' growth, understanding levels, and changing learning requirements, resulting in a more thorough and flexible approach to instruction (Klemke et al., 2018).

The advantages of DDFL extend beyond individual expertise. According to this study (Seng & Chuan, 2023), it increases student engagement, leads to better learning gains, and even improves teaching effectiveness. Educators obtain crucial insights on how their students learn, allowing them to modify their approaches and create a genuinely dynamic learning environment.

DDFL, like every other breakthrough, has its unique set of problems. Data privacy necessitates caution, and instructors must be trained to leverage the value of learning analytics. In order to support this data-driven strategy, schools may need to invest in digital infrastructure. However, when evaluated against the possible advantages, these obstacles appear to be minor hiccups

on an otherwise bright road. Data-driven flipped learning hints at a future in which learning is individualized, entertaining, and ultimately more rewarding for both students and instructors.

## CASE STUDY

In this section, we will dive deeper into the details of the experiment that was carried out using the innovative Data-Driven Flipped Classroom model. We will examine the specific population that was the focus of the study, the criteria for inclusion, and the resources that were utilized on the Blackboard LMS platform to drive this data-driven approach.

### **Course Description**

The algorithmic course serves as the foundation of our first year engineering program, giving students the fundamental knowledge and skills necessary to solve problems and engage in computational thinking in order to effectively deal with the complexities of contemporary engineering. Three years ago, first year student had a one programming course in their syllabus that covered algorithms alongside the C programming language. The emphasis was primarily on the language itself, delving into its specifications, including syntax and lexical features, with relatively less emphasis on problem-solving approaches.

As a result, we decided to add a new course to the syllabus focusing on algorithms and follows the same outcomes schedule of the other C programming course. Both courses have the same learning outcomes. The algorithm course focuses more on fundamental aspects and the problem-solving skill while the C programming course focuses on the application on those fundamental concepts and technical skills. Hence, Students are exposed to the learning outcome one week before the C programming course. Therefore, our challenge is to prepare students well enough to easily master programming courses, to solve complex problems in a pre-prepared way. Students will be more prepared to solve problems using model thinking.

Although the traditional lecture format was used in our algorithms course, we soon realized its shortcomings when it came to fully grasping and applying these intricate concepts. Passive learning, which characterizes traditional classroom, limits active engagement and practical application, which runs counter to the need for algorithmic learning, where students need to be engaged in analysing problems and formulating solutions. In addition, the lack of timely feedback mechanisms hinders personalized learning experiences. The classical approach used in this course is illustrated in figure 1.

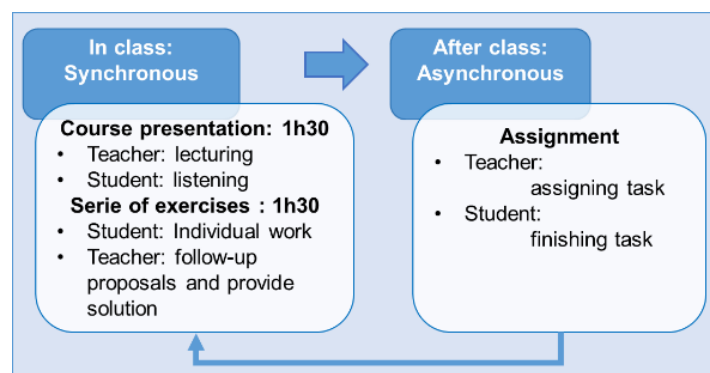


Figure 1. Overview of conventional teaching approach

As demonstrated, the course presents a limited interactivity between students, which reduced opportunities for collaborative problem-solving and diverse perspectives. Hence, we implemented the DDFL method in the algorithmic course and detail the outcomes in this study.

### ***Research questions and methods***

The aim of the study was to compare the effectiveness of the data-driven flipped classroom (DDFL) versus the traditional lecture-based teaching method in terms of improving the results of first-year computer engineering students. Research questions included:

The impact of the data-driven flipped classroom on student performance and understanding compared with the traditional lecture-based teaching method. The influence of data-driven personalized instruction on student engagement and academic achievement. The benefits and challenges of implementing the data-driven flipped classroom in a computer engineering teaching context.

To answer the research questions, the experiment involved two groups of First-Year Computer Engineering students at ESPRIT School of Engineering, totaling 120 participants. To ensure comparability with a focus on current learning dynamics, the experimental group (N=60) participated in the Data-Driven Flipped Classroom during this academic year, while the control group (N=60) experienced the traditional lecture-based teaching method in the previous academic year.

Selection criteria were used to maintain comparability between academic years. Students were chosen based on the following criteria: (i) Similar academic backgrounds. (ii) No past exposure to the model. Using these criteria, we hoped to create two comparable groups, even though they were from different academic years. This enabled a more accurate evaluation of the DDFL model's effects on student outcomes.

In summary, the study methodology involved a comparison between two groups of students to assess the impact of the data-driven flipped classroom on computer engineering students' performance and understanding, with a focus on teaching personalization and current learning dynamics.

### ***Design and Implementation of the DDFL Approach***

Our Data-Driven Flipped Learning Approach employs pre-class quizzes and in-class activities to customize the learning experience and cater to students with varying levels of knowledge in the classroom. The platform for providing the Data-Driven Flipped Classroom experience was Blackboard LMS.

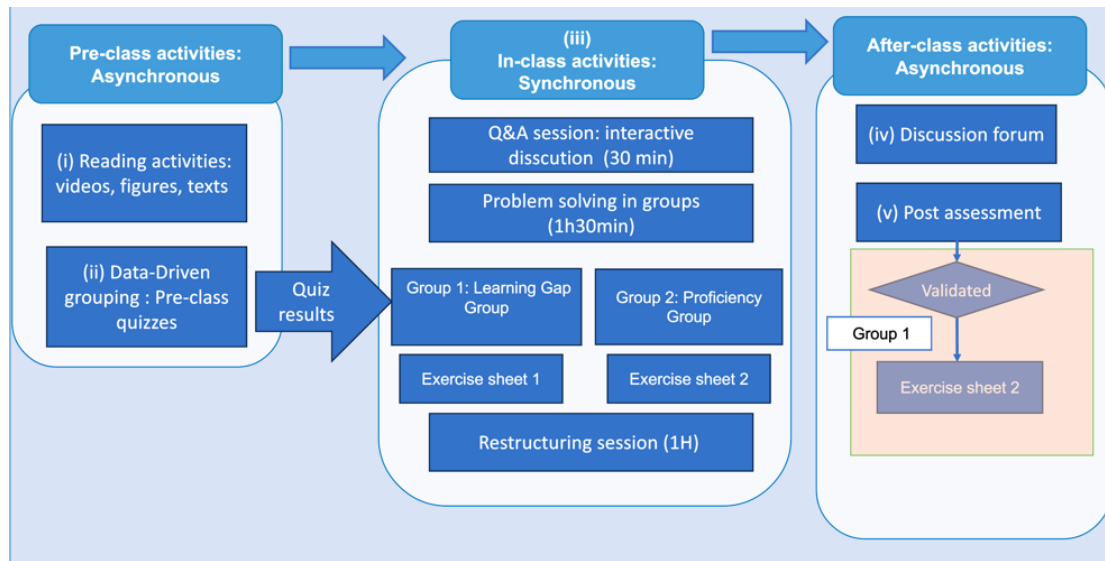


Figure 2. DDFL framework

This strategy consists of five components as illustrated in figure 2:

- (i) Pre-class Activities: Reading activities and video to address the learning outcome.
- (ii) Data-Driven Grouping and Pre-Class Quizzes: Before each class session, students take short, interactive quizzes to assess their understanding of significant concepts covered in pre-class lectures. Students are dynamically separated into two groups based on their quiz results:
  - a. Students in Group 1 (Learning Gap Group) score below a specified level, suggesting possible gaps in knowledge.
  - b. Students in Group 2 (Proficiency Group) have a medium or high level of understanding and score at or above the threshold.
- (iii) Activities in the classroom:
  - a. Q&A session: The instructors provide a clarification on doubts that arose from the pre-classes activities.
  - b. Collaborative problem-solving: Students work in groups depending on their Pre-Class Quizzes classification on a complementary set of exercises enabling cooperation on difficult tasks, boosting peer learning. Learning Gap Groups will have access to an exercise sheet of medium difficulty allowing the students to achieve the minimum level of learning outcome. While the Proficiency Groups work on a different set of exercises of higher level of difficulty allowing them to work to obtain a better level of understanding. Meanwhile, instructors give tailored help in class based on pre-quiz scores, concentrating on areas of uncertainty identified for specific student groups.
  - c. Restructuring session: The instructors provide an in-depth explanation on the most crucial parts of the lesson.
- (iv) Discussion forums: Students were able to interact and enhance their learning outside of the classroom thanks to ongoing conversations on Blackboard platforms.
- (v) After-class Activities: Students will have access to a post assessment if validated by the of Learning Gap Groups, they will have access to the same set exercises previously provided to the Proficiency Groups in order to attain excellence.

As previously detailed, a variety of methods are used in the algorithmic course to collect extensive data regarding student performance. Pre-class quizzes using the Learning

Management System (LMS) Blackboard are the first step in the process. These quizzes serve as a basic assessment tool, providing an overview of students' prior knowledge acquired through the course materials. During the course sessions, classroom activities adapted to the specific needs and skill levels of each group of students are presented and practiced by the students. This adaptation is based on the results of the initial questionnaire and on ongoing assessments of performance during the course. Continuous monitoring occurs during in-class activities in which the professor supervises and assesses individual and group progress. This dynamic feedback loop helps to refine teaching strategies to meet the unique needs of the students.

Post-class assessments, accessible on Blackboard, provide an overview of course effectiveness. In particular, students in Group 1 with a lower skill level will be automatically directed to a series of additional exercises after passing the post-class assessment. This will ensure a progression in skill level for their ongoing learning path. This ensures an adaptive, data-driven approach to optimizing the learning experience in the algorithmic course. The Data-Driven Flipped Classroom concept seamlessly merged pre-class preparation, data-informed in-class activities, and continuous learning beyond the classroom walls by utilizing Blackboard LMS, allowing students to take ownership of their learning journey.

## RESULTS AND DISCUSSION

The rigorous performance evaluation of the DDFL model is based on three main elements: the student survey, the teacher survey, and a detailed analysis of exam results classified by learning outcome. We begin by detailing the results of the surveys.

### **Student and teacher survey**

We conducted an electronic survey of the 16 teachers of the algorithmic module and the students in five first-year classes. We received responses from 67 students, representing 42% of the total. And here below the results of the survey:

#### 1. Pedagogical reform has improved active student engagement?

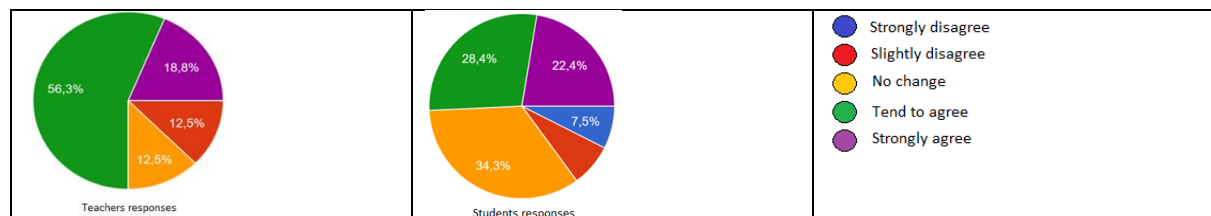


Figure 3. Evaluation of the impact of DDFL on active student engagement

Following on from these responses, we note that 70% of teachers have observed a better level of student engagement. For their part, more than half the students are better motivated. However, 15% of students are not more committed to this reform, which prompts us to launch future improvement actions. Indeed, when we analyze the students' responses more closely, going through their comments one by one, we find that those who are not satisfied with this approach find it difficult to assimilate the course in this phase. This is in line with the responses of a quarter of the teachers who are either neutral or slightly disagree with this approach and who added that in some chapters they found that the students did not assimilate it and they were obliged to repeat the course in class in the traditional way.



2. Flipped classroom activities (pre-assessment, vignettes, course materials) were helpful to prepare students for synchronous courses?

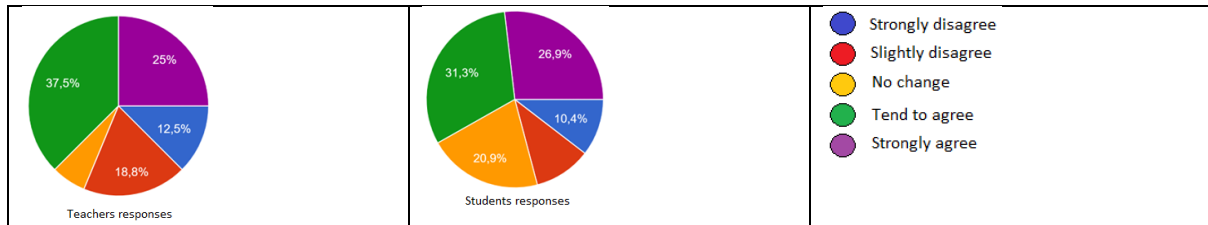


Figure 4. Evaluation of the effectiveness of the flipped classroom activities

Here we find that one-third of teachers would like to improve support. Also 20% of students think that supports are not suitable. This would lead us to better adapt the support to this new model.

3. The new learning activities helped students better understand the concepts.

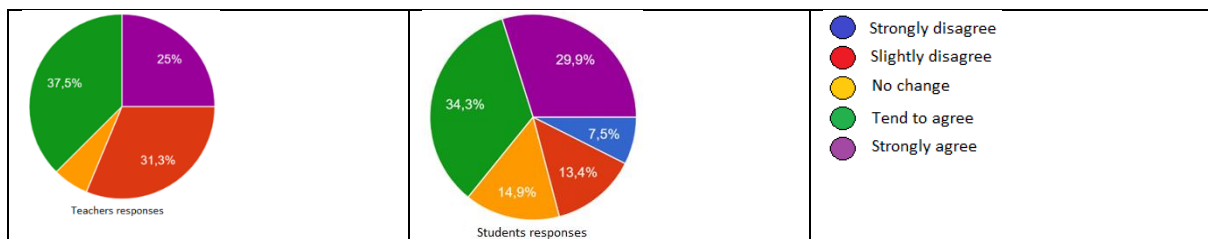


Figure 5. Assessing the impact of new learning activities

Although more than the half of teachers and students think that the new learning activities are suitable for understanding new concepts, we should improve these activities to be more adequate with our new approach. Both students and teachers who disagreed on this issue felt that more time was needed for synchronous sessions.

4. The process for allocating groups for teamwork was clear and fair?

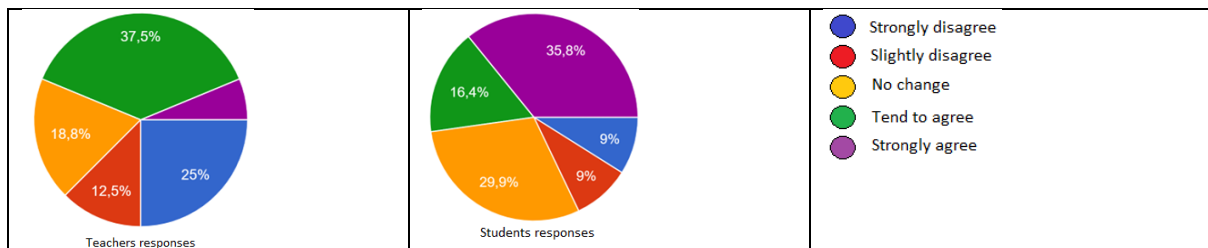


Figure 6. Assessing the process of groups allocation

More than 80% of students agree with the allocation of work groups, since it is based on pre-class results. On the other hand, over 35% of teachers think that the groups should be better distributed. This suggests that the pre-class phase could be improved.

5. The data-driven classroom model enabled appropriate personalization of learning?

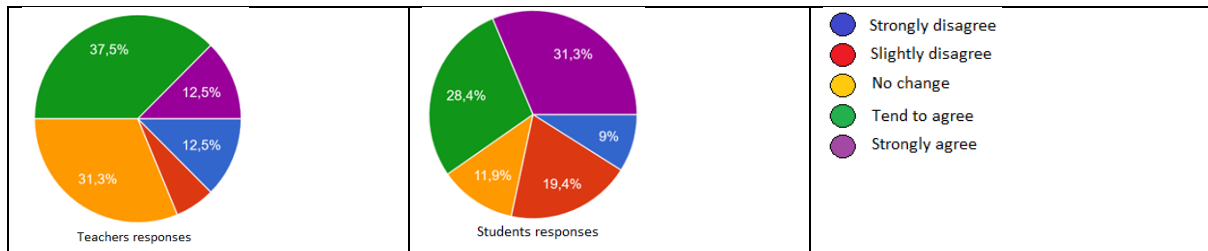


Figure 7. Evaluation of the data-driven model

We note here that students found the DDFL more personalized for them (60%). Indeed, students compare this approach with the flipped classroom approach in other modules such as programming. Although for both students and teachers the DDFL is more efficient, they all agree that more time should be allocated to synchronous sessions. Several students also suggested that correction of exercises not covered in class should be provided.

6. What specific aspects of the reform have been most beneficial in your experience as (a teacher of this module / a student in this module)?

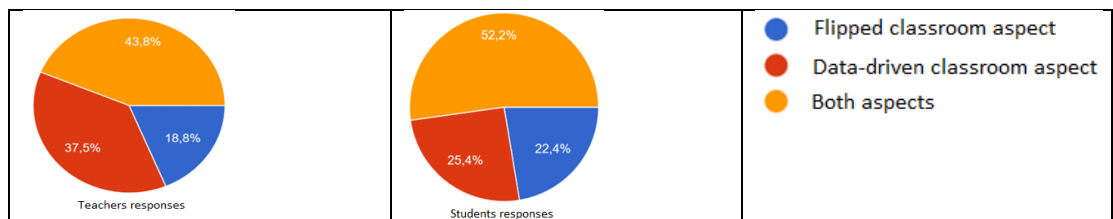


Figure 8. Evaluation of the DEFL approval rate

Teachers find DDFL more beneficial for students, although it involves more student monitoring. For their part, the students all agree that the flipped classroom is beneficial for understanding this module, but almost half are more inclined towards DDFL.

The conclusion of this questionnaire led us to the following results:

1. The students did not object to the group division as it was based on a test.
2. The DDFL requires more time to be allocated to synchronous sessions.
3. The course material needs to be continuously improved to ensure a better student understanding of the course.

**Evaluation of the rate of validation of learning outcomes**

The aim of the present investigation is to assess the impact of the pedagogical reform, centered on the DDFL approach, on the results of the assessment of students' learning outcomes in Algorithms during the academic years 2022-2023 and 2023-2024. The results, expressed as percentage of validation of learning outcomes (LO - Learning Outcomes), are illustrated in Table 1.

Figure 9 shows the significant changes in student performance following the implementation of this new approach. The overall results show a significant increase in student performance in algorithmics following the implementation of the DDFL approach during the academic years

2023-2024. The emphasis will be on Learning Outcomes 1 and 2, which represent the module's foundational elements.

Prior to the reform, only 55.39% of students validated learning outcome 1, indicating a mixed understanding of basic algorithmic concepts. However, after implementing the DDFL approach, this percentage climbed significantly to 74.2%. This significant improvement suggests that the reform was especially effective at improving students' understanding of fundamental algorithmic concepts. An in-depth analysis also reveals the impact of the DDFL approach on initially struggling students (Group 1: Learning Gap Group). The findings show that this pedagogical approach was effective in targeting the lowest-performing students, providing them with personalised assistance and special attention to fill gaps in their understanding of fundamental algorithmic concepts. This significantly increased the validation percentage.

Table 1. Percentage of validation of learning outcomes before and after DDFL approach

| Learning outcomes | Description                                                       | Percentage of validation of learning outcomes |           |
|-------------------|-------------------------------------------------------------------|-----------------------------------------------|-----------|
|                   |                                                                   | 2022-2023                                     | 2023-2024 |
| LO1               | Identify the basic concepts of algorithms                         | 55.39%                                        | 74.2%     |
| LO2               | Establish a high-quality algorithmic solution for problem-solving | 44.12%                                        | 61.4%     |
| LO3               | Use static data structures in programming activities              | 45.86%                                        | 58.69%    |
| LO4               | Apply good practices of procedural programming                    | 64.95%                                        | 66.6%     |
| LO5               | Recognize the role of an algorithm                                | 33.90%                                        | 57.43%    |

Another interesting observation is learning outcome 2, which refers to students' ability to develop high-quality algorithmic solutions. Prior to the reform, the validation percentage was 44.12%, indicating challenges in solving algorithmic problems and developing high-quality algorithmic solutions. After implementing the DDFL approach, the percentage increased to 61.4%, indicating a significant improvement in this particular skill. The DDFL approach allowed personalised teaching to better meet the specific needs of learners, particularly those who had difficulty establishing correct, quality algorithmic solutions.

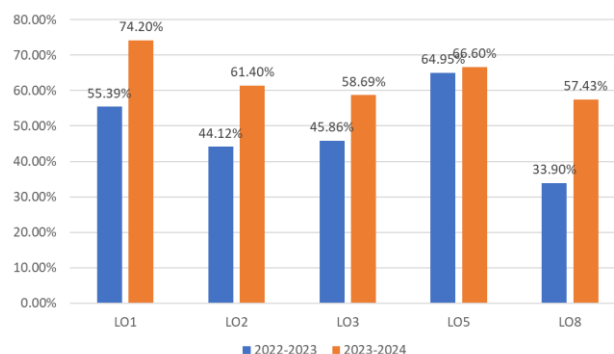


Figure 9. Written exam results before and after DDFL approach

Finally, the overall analysis of the results demonstrates the effectiveness of the DDFL approach in improving student performance in algorithms. The DDFL approach gave the weakest students a great opportunity to improve their understanding and make significant progress in key skills. This highlights the importance and positive impact of DDFL in the teaching context.

## CONCLUSION

This study is a significant investigation into the integration of the data-driven flipped classroom within the algorithm course. Faced with the challenges inherent in the traditional algorithmics teaching model, this study proposed an innovative model aimed at meeting students' diverse needs while improving learning outcomes. The initial context demonstrated the limitations of a one-size-fits-all approach to managing classes with varying levels of assimilation, which limited the achievement of learning objectives. The proposed data-driven flipped classroom model is a step towards a more adaptive, personalised learning environment.

Experimentation with first-year computer engineering students at the ESPRIT engineering school has provided valuable insights. The careful planning of learning activities, which included pre-class quizzes, in-class interventions, post-class discussion forums, and evaluation, proved successful. The experimental study's results, which compared the experimental group to the control group, revealed significant improvements, particularly among the students who had previously performed unfavourably. The positive impact of the data-driven flipped classroom model on students' problem-solving abilities, as well as its overall benefits evidenced by written exam results, underline its transformative potential in the field of algorithmic education. The model presented, therefore, positions itself as an effective solution for teachers wishing to stimulate student engagement and improve performance in this key area of computer science.

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# ENHANCING ENGINEERING EDUCATION THROUGH INTEGRATED PROJECTS AND PROJECT FAIR: A CDIO FRAMEWORK PERSPECTIVE

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## ABSTRACT

Engineering education is evolving to meet the demands of a dynamic professional landscape. At ESPRIT School of Engineering, we have embraced active learning methodologies, specifically problem-based learning, to cultivate a dynamic educational environment that effectively fosters the acquisition of practical skills among our engineering students. Our commitment to providing authentic learning experiences is exemplified through the integration of Integrated Projects into our curriculum. Aligned with the CDIO framework—Conceive, Design, Implement, Operate—these projects immerse students in real-life problem-solving scenarios. A unique facet of our curriculum is the introduction of the "Project Fair" experience, an event that combines project-based learning with sustainability inclusion and collaboration with industry partners. In essence, Project Fair is an extension of our commitment to the CDIO framework, providing students with a platform to showcase the results of their projects in a professional context. This event not only highlights the "Operate" phase but also actively involves stakeholders such as students, faculty members, administrative staff, and representatives from the industry. In this paper, we delve into the intricacies of the 10th edition of Project Fair, offering a detailed examination of how it aligns with CDIO standards. Our focus extends to the steps taken to involve businesses in the evaluation process, our emphasis on the United Nations' 17 Sustainable Development Goals (SDGs), and the active participation of alumni in enlivening the event. We outline meticulously planned steps crucial for the success of this event, involving the coaching process, a sophisticated evaluation method, and the efficiency of the organizing committee.

## KEYWORDS

Project based learning, Active learning, Teamwork, Innovation, Sustainability, SDGs, Standards: 2, 5, 6, 7, 8, 11.

## INTRODUCTION

Engineering students acquire skills that can be applied effectively in their professional careers. Active learning approaches, such as problem-based learning, create dynamic environments that stimulate authentic situations fostering skill acquisition. Numerous engineering education

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studies provide insights into the best practices associated with implementing Project Based Learning (PBL). This pedagogical approach serves as a learning framework that mirrors the challenges and complexities encountered in professional engineering practice. Moreover, the CDIO Syllabus (Crawley et al., 2014) emphasizes the integration of project-based learning experiences to enhance student learning outcomes. Furthermore, PBL stands out as a pedagogical approach especially beneficial within the context of CDIO design-implement courses (Edström & Kolmos, 2012). PBL and CDIO can play compatible and mutually reinforcing roles, and thus can be fruitfully combined to reform engineering education (Edström & Kolmos, 2014). This paper aims to introduce the implementation of PBL at ESPRIT, present the Project Fair as an authentic learning experience, and highlight the quantifiable achievements of the 2023 edition of the event. Indeed, the Project Fair is a key event to celebrate and exchange ideas on the issues and challenges of future and emerging technologies which are the crucial parameters of any digital makeover. Its ability to mirror real-world scenarios needs engagement with stakeholders, and the event serves as a conduit for networking opportunities. In addition, we have strategically incorporated the SDGs into the evaluation process, emphasizing the awareness of sustainability issues related to the 21st century. Our commitment to sustainability extends beyond the event, with alumni actively contributing to its success and bringing attention to the importance of sustainability in engineering education. Furthermore, the event fosters a competitive environment among projects, with exceptional ones receiving well-deserved recognition and prizes. This paper is structured as follows. Section 2 exposes the project-based learning approach of ESPRIT. Section 3 presents the Project Fair event and the schedule followed to ensure effective organization. Section 4 offers insights into the 10th edition. In Section 5, we elucidate our adherence to CDIO standards. Section 6 highlights the impact of this event on students and faculty members. The last section is devoted to providing a conclusion that encapsulates the details outlined in the paper.

## **ESPRIT CASE OF STUDY**

Active learning approach promotes original learning situations and better support for engineering students. ESPRIT school of Engineering emphasizes the development of durable skills for its students through specialized course offerings, projects, career fairs, and internship opportunities. ESPRIT on the other hand, adopts active learning, particularly problem-based learning (PBL) through integrated projects. These projects are effectively achieved in alignment with the CDIO principles (Conceive-Design-Implement-Operate) providing learners with real-life scenarios and fostering original learning situations for better support. The intensive utilization of project-based learning is one of the main provisions of the CDIO initiative (Crawley et al., 2014). This approach not only emphasizes theoretical knowledge but also hones the practical skills essential for success in their future professional endeavors. Obviously, faculty members establish clear guidelines and expectations for industry involvement to ensure that students' learning outcomes are met. Hence, students not only deepen their theoretical knowledge but also develop practical skills necessary for their professional growth. Students must work in teams and apply these various skills and knowledge areas. But how is it possible to give our students the opportunity to have feedback on their work from industry and encourage collaboration between our faculty members and experts who can offer real problem situations. Indeed, (Carlson, 2017) discussed these potential challenges specific to engineering education and considered that instructors must stay up to date with industry developments to design appropriate problems. This underscores the importance of creating opportunities for students to interact with industrial companies to contribute to the development of their competences, as highlighted by (Mazini et al., 2018).

Another challenge lies in ensuring sufficient resources and support for faculty members to effectively facilitate PBL. Additionally, fostering a culture of awareness about sustainability and integrating it into engineering education is another significant challenge. At ESPRIT, we are committed to refining our implemented PBL approaches continually. Our aim is to ensure that engineering students are not just academically proficient but also well-prepared for the multifaceted demands of the professional engineering landscape.

## **PROJECT FAIR PRESENTATION**

Project-based learning has been a subject of exploration for numerous researchers, to engage students in authentic, real-world tasks to enhance learning. Obviously (Kokotsaki et al., 2016) offers an in-depth review of existing research on this pedagogical method. Examining previous studies, the authors explore the effectiveness of project-based learning and its potential benefits and challenges. This survey provides a solid foundation for understanding key trends and findings in the field, which is essential for guiding future research and informing pedagogical practice. Within engineering, (Zhou & Valero, 2016) have drawn attention to the promotion of creativity in students' projects. (Mozgavela et al, 2014) explore the gamification experience of students' project activity, shedding light on innovative approaches to project-based learning. In this section, we present the ESPRIT Project Fair as an authentic learning experience, outlining the goal, audience, and organization. Project Fair is a prominent end-of-year celebration which takes place annually at the end of the academic year at ESPRIT. It is considered as the school's flagship event during which ESPRIT students (from the 1st to the 4th year, all majors and specialties combined) showcase the projects they work on during the year with a lot of creativity and professionalism. In addition to integrated projects, ESPRIT offers this experience to combine project-based learning, sustainability inclusion and collaboration with industry. In line with our commitment to CDIO standards, this experience distinguishes itself from common authentic learning situations. It scales to larger classes and multiple sections and maintains the benefits of PBL while managing larger groups of students. Each year this event highlights our best practices about the inclusion of active teaching methods in our learning environment. Our goal is to create a setting that promotes collaboration and empowers students to take responsibility for their learning. Consequently, the Project Fair helps in the popularization of project-based learning, puts learners in a competitive environment which boosts innovation. To encourage engineering trainees, the standout projects realized by our students are exposed to emphasize their technical, communication and teamwork skills. Moreover, this event is a fully-fledged quality culture in which all stakeholders including students, faculty members administrative staff, and companies are involved. Hence, hundreds of visitors; families, instructors, partners; professionals, and business owners attend this event to discover the expertise and diligence of our students in coming up with brilliant solutions to real-life issues. As a result, Project Fair provides an exceptional platform for students to showcase their work through the organization of exhibition spaces, interact with a diverse audience, and receive feedback in a professional context. Over an academic semester, assiduous and meticulous work is undertaken within the various modules, which emphasize a project-based learning approach. Each of these modules rigorously implements the first three phases of the CDIO framework: "conceive", "design" and "implement". The project fair takes on particular importance in highlighting the "operate" phase, offering students an unprecedented opportunity to present the concrete results of their projects to a wide and diverse audience. To highlight the achievements presented by our engineering students at this event, we generate a catalog highlighting the most outstanding projects from each edition. This catalog will be shared with a wider audience later. Elsewhere, to reach a diverse audience mirroring real-world scenarios, students must effectively communicate and



convey their work in a manner accessible to non-experts. This platform facilitates a competitive comparison with other projects and the outstanding ones consistently receive recognition and prizes. Finally, this event comes as a coronation of all the efforts deployed by students and faculty members by setting up Project/Problem-Based Learning as a training approach and aiming to provide the job-market with readily employable 21st century engineers.

### **Agenda**

Given that this event crowns the efforts of students and teachers throughout the academic year, its organization must be carefully planned. This will require a significant time investment to consider all details, ensuring the selection of the best projects and the recognition of the deployed efforts based on a clear and fair evaluation process using measurable criteria. Consequently, we have developed a schedule spread over the entire year, detailing the necessary steps for the success of our flagship event. The table below outlines this plan.

Table 1. Project Fair agenda

| <b>One Year Before the Event (Year N-1)</b> |                                                                                                                                                                                                                                                                                                                                                           |
|---------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>When</b>                                 | <b>What to do</b>                                                                                                                                                                                                                                                                                                                                         |
| <b>June</b>                                 | <b>Retrospectives</b> <ul style="list-style-type: none"> <li>- Production of the catalog showcasing the projects participating in the N-1 edition.</li> <li>- Collecting feedback from the N-1 edition</li> </ul>                                                                                                                                         |
| <b>July</b>                                 | <b>Collection of proposals for</b> <ul style="list-style-type: none"> <li>- Updating</li> <li>- Themes</li> <li>- Evaluation method</li> </ul>                                                                                                                                                                                                            |
| <b>September</b>                            | <b>Initiation of event preparations</b> <ul style="list-style-type: none"> <li>- Introduction of the Fair Appointment of committee</li> </ul> <b>Finalization and announcement of</b> <ul style="list-style-type: none"> <li>- Evaluation criteria</li> <li>- Awards</li> <li>- Theme</li> </ul> <b>Solicitation of companies to offer specifications</b> |
| <b>October</b>                              | <ul style="list-style-type: none"> <li>- Preparation of the sponsorship file</li> <li>- Identification &amp; Solicitation of sponsors</li> </ul>                                                                                                                                                                                                          |
| <b>November</b>                             | <ul style="list-style-type: none"> <li>- Validation and announcement of the number of participating teams per level/specialization</li> <li>- Contact student clubs</li> </ul>                                                                                                                                                                            |
| <b>December</b>                             | <ul style="list-style-type: none"> <li>- Pre-selection of participating teams for 1st semester projects</li> </ul>                                                                                                                                                                                                                                        |
| <b>January - February</b>                   | <b>Launch of organization activities</b> <ul style="list-style-type: none"> <li>- Setting up tools &amp; virtual or physical structures.</li> <li>- Definition of media and corporate communication strategies</li> <li>- Preparation of visuals, press releases, etc.</li> <li>- Re-establish contact with student clubs.</li> </ul>                     |
| <b>March</b>                                | <ul style="list-style-type: none"> <li>- Planning the sequence of events (running order, speakers, participants, evaluators, opening and closing remarks)</li> </ul>                                                                                                                                                                                      |

|              |                                                                                                                                                                                                                                                                                                                                                                                              |
|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|              | <ul style="list-style-type: none"> <li>- Development of the D-Day program</li> <li>- Drawing up animation program</li> <li>- Contacting the media</li> </ul>                                                                                                                                                                                                                                 |
| <b>April</b> | <ul style="list-style-type: none"> <li>- Selection of participating projects &amp; retrieval of student outputs for use in creating projects catalog (capsules, descriptions, posters, etc.)</li> <li>- Solicitation of companies to involve them in the evaluation process.</li> </ul>                                                                                                      |
| <b>May</b>   | <p><b>Finalization of organizational activities</b></p> <ul style="list-style-type: none"> <li>- Finalization of tools &amp; virtual or physical structures</li> <li>- (D-15) Media coverage and solicitation of companies as guests</li> <li>- (D-7) Broadcast the event on social networks.</li> <li>- Raising awareness of the need for teachers &amp; students to participate</li> </ul> |

## 10TH EDITION

This edition was distinguished by the diverse range of disciplines represented by the participating teams. There were participants from fields such as computer science, telecommunications, civil engineering, and electromechanics. As a result, there was a considerable breadth of topics covered. The table below offers a comprehensive overview of the showcased projects, exploring a diverse range of fields and topics they encompass, thus providing a multifaceted understanding of their content and themes.

Table 2: Fields/Topics

| <b>Field</b>     | <b>Topics</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <b>Number</b> |
|------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|
| Common core      | Serious Game on sustainable development<br>Municipal election management<br>Smart Airport, Smart Radio, Smart Court, Smart travel Agency,<br>Smart event planner, Smart coworking space, Smart RDI center,<br>Smart Electric charging station, Smart Ambulance agency, Smart<br>Technical Visit center, Smart ADHD center, Smart Share and<br>Care center<br>Barter / Catering / Automotive<br>Transport, Freelance and employability, Art and culture,<br>Environmental awareness and sustainability, Health and wellness,<br>Finance/Insurance/Fintech, Sport/e-sport gaming | 43            |
| Computer Science | Health, E-learning, Art<br>Employment/Recruitment/HR<br>Real Estate, Home services<br>MarketPlace/E-commerce<br>Social network<br>Monitoring<br>Electronic Banking<br>Bioinformatics<br>Microinsurance/Microfinance<br>Fintech<br>E-sport                                                                                                                                                                                                                                                                                                                                      | 30            |

|                    |                                                                                                                                                                                                                                                                 |    |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Telecommunications | Cybersecurity SOAR XDR SIEM SOC<br>Mhealth, MEducation , Smart APP, AI, Blockchain,<br>Internet of things, M2M<br>Metaverse<br>Serious games<br>Addictive online multiplayer games<br>User Experience in 5G Networks/ failure prediction in<br>IP core networks | 58 |
| Civil Engineering  | Urban planning and sustainable development<br>Critical study of a work<br>Sustainable construction and the environment<br>Building physics<br>Building structures<br>Structures and structures                                                                  | 11 |
| Electromechanics   | Electromecanic systems<br>Robotique et IA                                                                                                                                                                                                                       | 18 |

In this section, we take a closer look at the unique experience of the 10th edition of this event, focusing on the CDIO standards covered. We highlight the quantifiable achievements of the 2023 Edition of the ESPRIT Project Fair as shown in Table 3, then we present committee information, evaluation process, and sustainability inclusion.

Table 3 Quantifiable Achievements of the 2023 Edition

| Achievement                             | Number |
|-----------------------------------------|--------|
| Numbers of participating students       | 1000   |
| Number of Stands                        | 195    |
| Number of participating companies       | 20     |
| Number of participating faculty members | 400    |
| Number of winning teams                 | 43     |
| Number of prizes awarded by companies   | 5      |

### **Committee information**

Setting up the organizing committee proved crucial. This committee was carefully put together, including six sub-committees, each responsible for a specific area of activity: sponsoring, communication, digitalization, evaluation, logistics, D-Day program, and logistics. This approach enabled us to ensure detailed management of every aspect of the event, while perfecting efficiency. We followed a series of well-planned steps which led to ensure the success of this event. The table below gives an overview of the different tasks carried out by each sub-committee.

Table 4. Sub-committee missions

| Sub-committee  | Missions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sponsoring     | <ul style="list-style-type: none"> <li>- Budget estimate.</li> <li>- Draw up sponsorship file.</li> <li>- Identify &amp; Solicit companies to sponsor the event and give prizes to the winners in recognition of their efforts.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                             |
| Communication  | <ul style="list-style-type: none"> <li>- Create a press release for distribution to the media and public, to communicate concisely and informatively about the event.</li> <li>- Development of a complete communications and media strategy</li> <li>- Contact the media (TV, radio, digital magazines, etc.) to ensure good media coverage aiming to motivate students and raise the profile of their achievements among a wide target audience.</li> <li>- Design of visual communication media (roll-ups, stickers, logos)</li> <li>- Development of a catalogue showcasing the participating projects.</li> </ul> |
| Digitalization | <ul style="list-style-type: none"> <li>- Preparation of the resources of the virtual version of the Fair.</li> <li>- Posting promotional video clips for participating projects on our YouTube channels.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                    |
| Logistics      | <ul style="list-style-type: none"> <li>- Drawing up a plan for stand layout.</li> <li>- Reservation of required equipment: data show, power strip, screen, table, chair, internet connection, etc.</li> <li>- Setting up tools &amp; virtual or physical structures</li> </ul>                                                                                                                                                                                                                                                                                                                                         |
| Evaluation     | <ul style="list-style-type: none"> <li>- Definition of selection criteria for participating projects and development of criteria grids ...</li> <li>- Invite professionals to take part in the evaluation process.</li> <li>- Assigning evaluators</li> <li>- Prepare certificates of excellence for distribution on the D-Day</li> </ul>                                                                                                                                                                                                                                                                              |
| D-Day program  | <ul style="list-style-type: none"> <li>- D-Day program: speeches, stand visits, music, clubs, prize-giving, photo shoots.</li> <li>- Planning the flow of the event.</li> <li>- Prepare a parallel entertainment program involving student clubs.</li> </ul>                                                                                                                                                                                                                                                                                                                                                           |

### ***Evaluation process***

It all started with in-depth coaching of the students throughout the PBL sessions. Then, the creation of a sophisticated evaluation process was essential. We developed a suitable assessment method using detailed evaluation grids. These grids are based on specific criteria, taking into consideration a variety of skills and learning outcomes. This thorough evaluation ensured that every aspect of the event was aligned with our goals of quality and excellence. The evaluation process started with the selection of the participating teams among 8000 students. To do so we used different criteria which are:

- The mark awarded to the project, equivalent to the average of the assessments of the various team members, is set up by the tutors based on an assessment grid specifically designed for this project.
- In addition to this, we give 20% to assess the team's level of motivation and 20% to recognize the innovation of ideas.
- An evaluation of the advertising video designed by the team to promote their final deliverable.

The next stage involves selecting a winning team for each project, based on further evaluation criteria. Depending on the number of participating teams per project we may have a single round if the number is less than 7, otherwise, we'll opt for two rounds.

During the first stage of the two-round projects, the juries will be tutors with an in-depth understanding of the project details. They will be responsible for evaluating all teams to select the best five, from which a company expert will select the winning team.

For single-round projects, and in the second round for two-round projects, a guest expert from the professional community will carry out the evaluation to select the winning team for each project. This expert assessment aims to underscore the significant value added to the evaluation process, as their industry expertise and insights will contribute to selecting the winning team for each project. The appraisal criteria include competence in the use of technology, verbal, non-verbal and paraverbal communication skills, mastery of the language used to interact with the jury, quality of stand presentation, and consideration of sustainable development issues. In addition, visiting teachers who are not tutors will provide evaluations for each team, reflecting their appreciation of the project carried out. Furthermore, 10% of the score will be awarded according to the number of "likes" the video receives on YouTube. This edition involved businesses in the evaluation process, establishing contact between them and students. In addition, many alumni were committed to enlivening the event. The fair created a sense of pride and accomplishment not always present in everyday project-based learning.

### ***Sustainability inclusion***

The event put the spotlight on students' awareness of sustainability issues in the 21st century. Indeed, faculty members require support and training to effectively integrate the SDGs. This involves understanding the SDGs, designing appropriate problems, and assessing student learning. Therefore, we organized specific training sessions on the UN's 17 SDGs for our faculty members to ensure a comprehensive understanding of these global issues. To acknowledge the dedication of students who have considered the intricacies of sustainable development and proposed innovative solutions, our partners have generously provided three awards for the three best projects that offer sustainable solutions. A specialized jury, consisting of experienced educators in the field of sustainable development, played a pivotal role in selecting the winners. The selection process was meticulously guided by a criteria grid, focusing on the integration of SDGs within the projects and assessing the projects' overall impact on these globally recognized objectives. This initiative not only fosters a culture of sustainability but also encourages students to actively contribute to addressing the challenges outlined by the SDGs.

## **A CDIO FRAMEWORK PERSPECTIVE**

The CDIO initiative as articulated in the work by Crawley et al. (2014), focuses on setting specific learning outcomes for engineering students. This emphasis ensures that they not only acquire the appropriate foundation in knowledge but also develop skills and attitudes essential for engineering practice. In this context, ESPRIT's focus on the student life cycle and its dedication to developing employability for graduates are in accordance with CDIO project's goals. The project fair is particularly in line with CDIO standards and practices, as it focuses on integrating curricula, learning experiences, and outcomes to ensure that students acquire the necessary knowledge, skills, and attitudes for their future careers. Here's how the fair experience aligns with these standards:

CDIO Standard 2: The project fair provides students with specific, learning outcomes for personal and interpersonal skills, as well as product skills.

CDIO Standard 5: The project fair offers students opportunities to apply their knowledge and skills in real-world engineering problems.

CDIO Standard 6: The project fair environment supports student learning and development, providing access to resources and facilities necessary for their engineering projects.

CDIO Standard 7: The project fair experience encourages teamwork and collaboration among students working together on complex engineering problems.

CDIO Standard 8: The project fair promotes innovative teaching and learning methods.

CDIO Standard 11: The assessment approach during the Project Fair allows students to prove their learning outcomes and receive feedback on their performance, supporting continuous improvement and personal development.

CDIO Standard 12: The project fair contributes to the overall evaluation of the engineering program, ensuring that it delivers a high-quality education to students.

## **IMPACT FOR STUDENTS AND FACULTY MEMBERS**

The outcomes which indicate the success of this event are:

### ***Stakeholders' satisfaction***

Following the event, we launched a comprehensive survey form with a series of criteria for the various stakeholders. The aim was to gather detailed feedback on every aspect of the project fair. This initiative is part of our continuous improvement process, aimed at optimizing our processes and meeting the expectations of our community.

According to the results of a post-event survey, 74% of students and 90% of teachers expressed satisfaction with the organization and atmosphere. Communication during and after the event was appreciated by 76% of teachers and 80% of students. These results can be attributed to the fact that the quality of organization and communication has increased the visibility of our students' achievements, providing them with the opportunity to establish connections with professionals in the industry. As for the evaluation process, it met with the

approval of 84% of teachers and 55% of students. This has enabled us to assess the skills and technologies acquired by our students, along with identifying areas that could be enhanced.

### ***Industry involvement***

The Project Fair is structured to provide students with an exceptional opportunity to not only present their work through organized exhibition spaces but also to interact with a diverse audience, including industry professionals. The contribution of industry partners to the ESPRIT Project Fair plays a key role for both the school and the students. By involving them in the assessment process, we create a direct link between industry experts and our students, providing valuable insights into the skills demanded by the professional sphere. Students establish networking opportunities with potential employers, and faculty members foster meaningful connections with industry professionals.

### ***Alumni Involvement***

The active participation of alumni in the ESPRIT Project Fair holds significant importance, serving as mentors and animators. Their engagement contributes to the success of the event and plays a crucial role in the development of current students. Alumni bring invaluable insights into the industry and guide students offering practical advice and sharing their own career journeys. They provide a broader perspective on career paths and industry expectations. Connections with current students often extend beyond the event and lead to internships, job placements, and mentorship opportunities. In addition, alumni serve as animators during the 10th edition of ESPRIT Project Fair, and they energize the atmosphere. Overall, alumni participation enhances the impact of the Project Fair and contributes to the development of the students.

### ***SDGs Cover***

The incorporation of the United Nations' 17 Sustainable Development Goals helps translate 21st-century engineering skills into practical application. In the 10th edition of the project fair, the thematic focuses on " Integrating sustainable development issues into the training of engineers and managers " to highlights the crucial role of engineering in addressing global challenges and promoting sustainable development. By incorporating the SDGs in the Project Fair, students cultivate a sense of responsibility and awareness, essential for addressing the complex challenges of the modern world. Beyond immediate problem-solving, this approach encourages students to consider the long-term impact of engineering decisions on society, the environment, and the economy (United Nations, 2015).

## **CONCLUSION**

In this paper we presented the "Project Fair", an authentic learning experience which is a distinctive feature of our curriculum. After discussing implementation of the project-based learning approach at ESPRIT, we presented a series of carefully planned steps crucial for the success of our event. We started by detailing the crucial steps required to ensure optimal organization of this major event, given its scope involving various players. Focusing then on the tenth edition, we explained how we created sub-committees to give equal importance to all organizational aspects. This was accompanied by a sophisticated evaluation process, based on measurable criteria established using criterion grids. In addition, we integrated sustainable development issues to value solutions aligned with the Sustainable Development

Goals. Particular attention was paid to aligning this authentic educational experience with CDIO standards. Finally, we undertook an in-depth study to assess the impact of the event on both our students and faculty. This holistic approach aimed to comprehensively analyze the positive spin-offs and lessons learned from the experience, thus consolidating our commitment to educational excellence and sustainable development. To perfect communication for future editions, we are planning to create web and mobile applications. These applications will provide access to information on participating teams, while simplifying the evaluation process. To enhance the virtual version of the Project Fair, we are working on a metaverse-based solution. This will make it possible to carry out virtual visits remotely, guaranteeing extended visibility.

## FINANCIAL SUPPORT ACKNOWLEDGEMENTS

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# **CULTIVATION OF PROFESSIONAL ELECTROACOUSTIC TALENT USING CDIO INNOVATIVE TEACHING METHODS**

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## **ABSTRACT**

The purpose of this study was to apply Conceive-Design-Implement-Operate (CDIO) innovative teaching methods combined with Project Based Learning (PBL) to the cultivation of talent with the professional and technical knowledge required by the electroacoustic industry. The study period was three years, with the first and second semesters of each academic year considered one research cycle. The research subjects were first-year students in Feng Chia University's Master's Program of Electro-acoustics. There were a total of 34 students during the three years, working in teams of 3-4 students each. Headsets served as the research subject. First, students became aware of the development of electroacoustic market trends and the history of headphone brands (Conceive). Then, they learned how to construct the geometry of the components using CAD and simulated the acoustic radiation characteristics of headphones with equivalent circuit model (ECM) (Design). Subsequently, they remade headphones using CAD and 3D printer (Implementation). Finally, they compared the sound pressure characteristics of the physical and simulated earphones and optimized the design (Operation and Optimization). Their learning effectiveness was analyzed using pre-test and post-test questionnaires and rubrics. Results showed that learning effectiveness increased significantly by 65.2% following the introduction of the proposed innovative teaching model. The most significant results were in the Operation and Optimization stages, reaching more than 70.2%. This indicated that learning processes combined with PBL and hands-on practice can effectively improve students' motivation to learn.

## **KEYWORDS**

CDIO, Electroacoustics, Headphone, Questionnaire, Standard 5, Standard 6

## **INTRODUCTION**

Human resources are important assets in this era of the knowledge economy and a key factor for industrial upgrades and enhanced competitiveness. Facing an increasingly competitive

international market, any educator who is dedicated to improving the current education system must consider two issues: (1) The knowledge, abilities, and attitudes that students should possess when they graduate to be able to cope with the changing market, and the level of proficiency that they should achieve. (2) What educational institutions can do to ensure that graduates have the proper knowledge, abilities, and attitudes. These long-standing issues in engineering education also exist in the current cultivation of professional electroacoustic talent.

In recent years, one of the most successful and influential achievements in the international engineering education field has been the development of Conceive-Design-Implement-Operate (CDIO) innovative teaching methods, which have been promoted by Worldwide CDIO Initiative. In engineering education, these teaching methods have been inspired by the product development cycle, including process and system conception, design, implementation, and operation. Emphasis is placed on an integrated curriculum for students to master basic engineering theories and professional knowledge, through active and practical problem-solving, teamwork, and innovative practices, to acquire the capabilities required by engineers (Crawley et al., 2014).

Based on CDIO, Al-Atabi (2014) pointed out the themes and requirements for professional engineers at each stage of training. These are consistent with the training of electroacoustic professional technicians conducted by this institute. In 2017, Zarei et al. mentioned that engineering science education should include diversified learning resources to meet students' learning needs, while being adaptable to students' individual learning styles and speeds. The quality, accessibility, and acceptability of learning resources can be improved through appropriate design of mobile learning. Edström (2020) emphasized the importance of quality, suggesting that under the definition of a quality mechanism, work that is neither academic nor useful can be systematically eliminated and boundaries and standards can be defined.

Project Based Learning (PBL) is learner-centered and allows students to independently engage in design, problem solving, decision-making, research, and other related work to solve challenging problems (Jones et al. 1997, Thomas et al., 1999, Thomas, 2000). Edström and Kolmos (2014) have suggested that PBL and CDIO play compatible and complementary roles. Thus, they can be effectively combined to reform engineering education. In the assessment, Yajima et al. (2021) described that self-assessment, peer assessment, and teacher assessment after the PBL showed the improvement in the target skills. In a recent study, Boelt et al. (2022) further demonstrated the synthesis of generic competencies perceived by engineering students in a PBL environment and illustrated the landscape of generic competencies, providing a frame of reference for discussing strategies for developing the broad range of generic competencies required of future engineers as they address complex social challenges. Jun Suzuki et al. (2022) also verified the improvement of general skills (GSs) by using a cross-course-typed (integrated) PBL in one of Experimental subject 4<sup>th</sup> grade.

The Master's Program of Electro-acoustics, established at Feng Chia University (FCU) in 2007, is currently the only program that systematically cultivates electroacoustic professionals in Taiwan. It not only has a comprehensive teaching staff and software and hardware, but is also in line with domestic and foreign electroacoustic education in terms of teaching axes and curricula. The instructors are aware of current development needs of the industry, due to their close links to the domestic electroacoustic industry. Moreover, the curriculum is updated and redesigned every year in response to global electroacoustic trends. Before 2018, the foundation of this academic program was laid, while focusing on and continuously linking industrial needs and academic research, and accumulating technical energy and in-depth understanding of industrial needs. After 2018, it was recognized that the global electroacoustic

industry and relevant technology were undergoing rapid development, leading to an exponential demand for high-level electroacoustic talent. Therefore, understanding how existing resources, such as time, manpower and material resources, can be utilized to integrate relevant technologies and courses and cultivate more capable, high-level, electroacoustic technical personnel is the main motivation of this study.

## OBJECTIVE AND METHODOLOGY

### Objective

Based on the needs of the industry and continuous feedback on the curriculum and content of educational programs, there are 4 existing problems related to the linkage between curriculum and talent training: (1) Insufficient and coherent teaching; (2) Lack of interdisciplinary technology integration; (3) Lack of themes and non-interactive learning atmosphere; (4) Lack of professional depth and reporting capabilities. Therefore, improving the relationship between teaching and learning effectiveness to meet the electroacoustic industry's demand for technical talent is of major importance. In this study, a CDIO innovative teaching strategy was introduced and electroacoustic measurement methods were integrated with basic theory. Courses were the main teaching sites and PBL teaching method was selected, with headphone products as the target, to enable students entering this Master's degree program to systematically and completely absorb professional and technical knowledge, as shown in Figure 1.



Figure 1. Concepts for the cultivation of electroacoustic industry talent in this study.

### Methodology

#### Teaching Site

Two professional courses, Fundamental Acoustics and Electroacoustic Measurement and Methods, taught by the author in the first and second semesters were the main teaching and research sites in this study. Other courses, such as Electroacoustic Electronics and Electroacoustic Transducer Design, served as supplements, in addition to the involvement of professionals from electroacoustic enterprises. It was expected that through the introduction of diverse design elements and themes that learning desire and motivation could be significantly strengthened. Furthermore, students made use of international electroacoustic laboratories (Anechoic Chamber) and relevant measurement equipment (SoundCheck and KLIPPEL system), as shown in Figure 2, for learning and verification.



Figure 2. International electroacoustic laboratories and relevant measurement equipment.

### Research Objects

The research objects were mainly first-year students in the Master's Program of Electroacoustics. A total of 9 teams were formed, each with 3-4 students. Over the 3-year study period, there were a total of 34 students, as shown in Figure.3. A few electroacoustic industry professionals also attended the classes.



Figure 3. Research objects during the 3-year study period.

### Research Structure

With CDIO as the core and headphones the main target, each course was completed step by step, including the introduction of brand histories, classic headphone design concepts, CAD, simulation analysis, reverse engineering, and measurement verification, as shown in Figure 4.

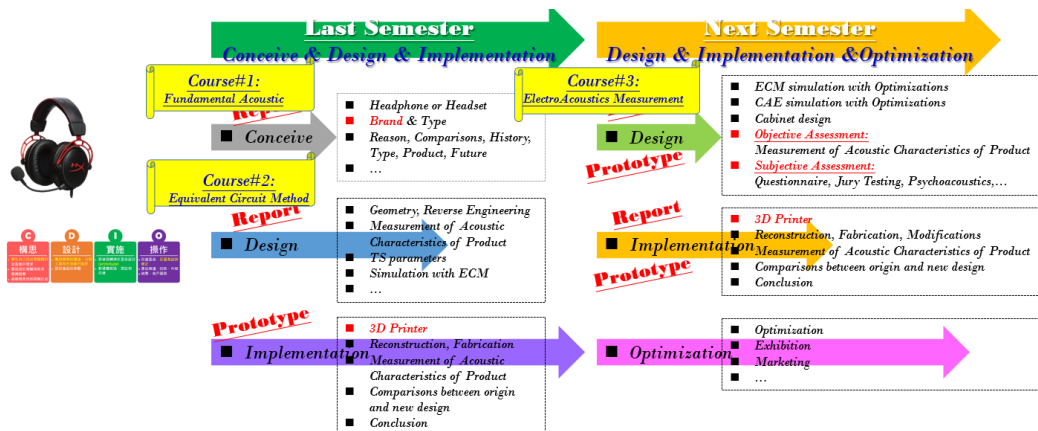


Figure 4. Research structure

## Research Assessment

To understand the learning effectiveness of students who participated in this innovative teaching model, we collected written and oral mid-term and final reports, encouraged mutual assessments of teachers and peers, and developed pre-test and post-test questionnaire with Rubrics evaluation method. Figure 5 and Table 1 show the assessment form and questionnaire. The questionnaire was divided into four major sections, according to the CDIO structure, made up of questions 1-6, 7-15, 16-19, and 20-22, respectively. Questions 23 and 24 were used to understand the level of agreement of students on whether this innovative teaching model should be applied to future electroacoustic talent training.

**ASSESSMENT**

|                                                                                                                                                                                                                                                                                                                                                                |                |          |  |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------|--|
| NUM. of TEAM                                                                                                                                                                                                                                                                                                                                                   |                | DATE     |  |
| HEADPHONE                                                                                                                                                                                                                                                                                                                                                      |                | REPORTER |  |
| MEMBERS                                                                                                                                                                                                                                                                                                                                                        |                |          |  |
| STEP                                                                                                                                                                                                                                                                                                                                                           | CONCEIVE       |          |  |
|                                                                                                                                                                                                                                                                                                                                                                | History        |          |  |
|                                                                                                                                                                                                                                                                                                                                                                | Classical      |          |  |
|                                                                                                                                                                                                                                                                                                                                                                | Others         |          |  |
|                                                                                                                                                                                                                                                                                                                                                                | DESIGN         |          |  |
|                                                                                                                                                                                                                                                                                                                                                                | Theory         |          |  |
|                                                                                                                                                                                                                                                                                                                                                                | ECM            |          |  |
|                                                                                                                                                                                                                                                                                                                                                                | Others         |          |  |
|                                                                                                                                                                                                                                                                                                                                                                | IMPLEMENTATION |          |  |
|                                                                                                                                                                                                                                                                                                                                                                | Assembly       |          |  |
| Measurement                                                                                                                                                                                                                                                                                                                                                    |                |          |  |
| Others                                                                                                                                                                                                                                                                                                                                                         |                |          |  |
| OPERATION                                                                                                                                                                                                                                                                                                                                                      |                |          |  |
| 3D Printer                                                                                                                                                                                                                                                                                                                                                     |                |          |  |
| Comparison                                                                                                                                                                                                                                                                                                                                                     |                |          |  |
| Others                                                                                                                                                                                                                                                                                                                                                         |                |          |  |
| COMMENT                                                                                                                                                                                                                                                                                                                                                        |                |          |  |
| GRADE                                                                                                                                                                                                                                                                                                                                                          |                |          |  |
| <input type="checkbox"/> A+ ; <input type="checkbox"/> A ; <input type="checkbox"/> A- <input type="checkbox"/> B+ ; <input type="checkbox"/> B ; <input type="checkbox"/> B-<br><input type="checkbox"/> C+ ; <input type="checkbox"/> C ; <input type="checkbox"/> C- <input type="checkbox"/> D+ ; <input type="checkbox"/> D ; <input type="checkbox"/> D- |                |          |  |

Figure 5. Assessment form and questionnaire

Table 1. Questionnaire question at each stage

| Steps        | Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CONCEIVE (C) | 1. I am familiar with the headphone brands on the market.<br>2. I have a favorite or familiar brand of headphones.<br>3. I know the history of headphone brands.<br>4. I understand the development of headphone brands.<br>5. I understand the characteristics of headphone brands.<br>6. I understand the monetary value of headphones on the market.                                                                                                                                                                                                                                                                                                                                               |
| DESIGN (D)   | 7. I understand the components of a headphone unit.<br>8. I understand the components of a headphone system.<br>9. I understand that headphone cavities affect frequency response.<br>10. I understand that a headphone cavity opening affects the frequency response.<br>11. I understand what an equivalent circuit is.<br>12. I understand the theory of equivalent circuits.<br>13. I understand how equivalent circuits are used in headphone unit simulation.<br>14. I understand how equivalent circuits are used in headphone system simulation (considering monomers and cavities).<br>15. I understand the TS parameters required by the equivalent circuit to simulate the headphone unit. |

|                                    |                                                                                                                                                                                                                                                                                                                                                          |
|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| IMPLEMENTATION<br>(I)              | 16. I understand the measurement of acoustic characteristics of headphone units.<br>17. I can compile my own program for measuring the acoustic characteristics of headphones.<br>18. I can operate the headphone acoustic characteristics measurement program by myself.<br>19. I can interpret headphone acoustic characteristics measurement results. |
| OPERATION<br>(OPTIMIZATION)<br>(O) | 20. I know about 3D printers.<br>21. I can operate a 3D printer by myself.<br>22. I can troubleshoot problems during the 3D printing process by myself.                                                                                                                                                                                                  |
| OTHERS                             | 23. I recommend that this topic continue to be used in electroacoustic training programs.<br>24. I like the course content and planning of this topic.                                                                                                                                                                                                   |

## RESULTS AND DISCUSSION

This study was conducted over 3 years, 2018, 2019 and 2021, and focused on the cultivation of electroacoustic industry talent, especially in terms of the recognition, design, measurement, simulation, and remaking of electroacoustic products, such as headphones. During this period, a total of 9 headphone products including DENON-HP700, ATH-AR1, Cooler Master MH751, JVC HA-FW10000, AKG K815LE, KOSS Porta Pro, ATH-M50x, AKG-K52, and RAZER Black Shark V2 X were studied and remade. The price of these headphone products ranged from TWD \$2,000-4,000 and the diameter from 40 mm-50 mm. In Figure 6 is presented a flow chart completed by one of the student teams for a specified headphone product. Each headphone product underwent acoustic characteristics testing, disassembly, component graphics drawing, simulation comparison, 3D printing, reassembly, and comparison verification.



Figure 6. Flow chart for the remaking of headphones in this study.

### Remade Headphones

Figure. 7 shows that each group of students was able to successfully remake headphones. Almost all comparisons were good. In addition, first-year students were encouraged to participate in the International Electroacoustic Forum and present posters. Figure 8 shows the posters produced by each group of students according to year.



Figure 7. Results of the remade headphones and verifications between simulation and measurement.



Figure 8. Posters of the 3 teams in the first year (2019)

### Learning Effectiveness

The statistical results for learning effectiveness each year and the averages of 3 years are summarized in Figure 9. The overall 3-year averages for the 4 sets of questions were between 1.05 and 1.26, among which Design and Operation stage scores were the lowest, 1.16 and 1.05, respectively. It is speculated that this is mainly because students had just entered the electroacoustics program and were still in the exploratory stage. Thus, most of their understanding of electroacoustics was based on what they had seen and heard in the past and personal preferences. However, most students had a considerable degree of motivation and desire to study electroacoustics based on the average score of 2.71 for questions 23 and 24.

At the end of the courses taught using CDIO and PBL methods, students' performance significantly improved. The overall average increased to 2.98~3.52, or more than 1.0 times when compared with the start of the class. From observations of student performance at each stage of CDIO, there were clear differences among the 4 learning stages of Conceive, Design, Implementation, and Operation, with averages of 57.9%, 67.3%, 65.4%, and 70.2%, respectively. The overall average growth was 65.2%. Among them, the best growth ratios were in the Operation and Design stages, respectively. The main reason is that in these stages students learned reverse engineering methods to complete the re-assembly of earphones and compare them with the original acoustic characteristic measurements. Since these processes required hands-on practice coupled with multiple adjustments and verifications by students, it was much easier to attract students' attention and improve their motivation and desire to learn.



From the analysis of the last two questions of the questionnaire, it was clear that students agreed that this innovative teaching model (CDIO with PBL) is of considerable help to those who are just entering the field of electroacoustics. Among the post-test results, the highest score of 5 points was given. Compared with the pre-test results, this was an improvement of around 2 times. In addition, students mentioned that due to the introduction of this creative teaching model, they not only developed a solid foundation in electroacoustic theory and technology, but also had the opportunity to learn about diverse electroacoustic technologies and find thesis topics. At the same time, people working in the electroacoustic company expressed that this model not only helps to cultivate electroacoustic professionals who meet the industry's demand for talent, but also effectively reduces the gap between learning and implementation.

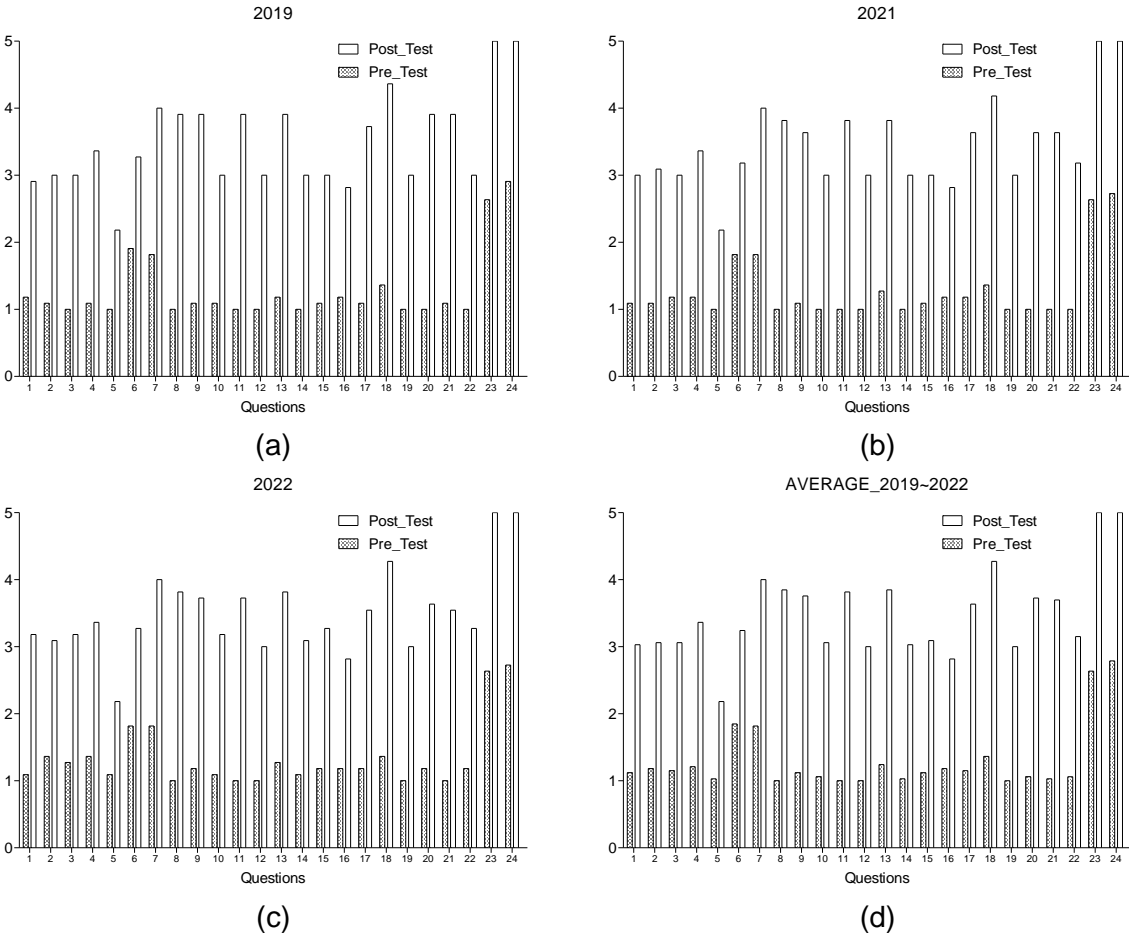


Figure 9. Statistical results of learning effectiveness of students; (a) each year; (b) average of 3 years

**CONCLUSION**

An innovative learning model of CDIO combined with PBL was proposed for the education of electroacoustic talent. The results showed that this model not only provides students with clear learning goals, but also systematically leads students in understanding electroacoustic industry trends, professional knowledge, theories, and technologies step by step, while simultaneously enhancing their motivation and desire to learn. This model also provides a solid foundation for

a two-year Master's program and a clear vision for thesis topics. The students trained using this creative model have received positive reviews and praise from their employers in the electroacoustic industry following graduation.

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# TEACHING REFORM AND PRACTICE OF SINGLE-CHIP MICROCOMPUTER COURSE BASED ON CDIO MODEL

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## ABSTRACT

In engineering education, it is critically important for theory teaching to be combined with practice. In order to achieve the teaching goals of a single-chip microcomputer (SCM) principles and interface technology course, the CDIO engineering education concept is introduced to solve practical engineering problems. On the basis of the CDIO engineering education outline, a task-driven teaching model with "Teaching, Learning & Doing" at its core is constructed. Basic knowledge and ability used in designing SCM application systems are covered in each real instance, and the practical ability of students is cultivated through the experimental course, individual projects and team cooperation projects. In team learning, each group consisting of 3–4 members is required to design a mechanical system or piece of equipment whose main control unit is an SCM. The design process should be divided into different parts, including market analysis and research, overall scheme demonstration and design, mechanical structure design, SCM control system design, system assembly and debugging, and technical and economic analysis. Finally, students will write technical reports to explain their projects and conduct on-the-spot system demonstrations during their defenses. The achievement of every group or group member is evaluated by peer assessment and teacher evaluation. Through the project study based on the CDIO model, students will understand that the development and application of microcomputer systems is an iterative and continuous improvement process. In order to obtain a high-quality product, every step in the process should be improved. When the course learning is finished, the performance of the students is generally evaluated by assignments, discussions, quizzes, experiments, individual reports, group work and the final exam. The above teaching practice is a significant enhancement demonstrated in the students' ability to develop SCM application systems, along with notable improvements in their engineering practice and innovation skills.

## KEYWORDS

CDIO concept; single-chip microcomputer; project-driven; active learning; learning assessment. Standards: 1, 5, 6, 7, 8, 11

## INTRODUCTION

The characteristics and superiority of the single-chip microcomputer (SCM) determine its universal application. Due to its intellectual potential, strong interface driving capability and low power consumption, the SCM has been widely used in industrial, information and household appliance fields, with the application techniques changing rapidly. In recent years, SCM-applied technical talents have been in great demand. As SCM technologies are updated in China and abroad, all colleges and universities are accelerating the development of SCM courses and research on teaching reform. To satisfy the need to cultivate high-level applied talents, enhancing course construction and reform is a focus of teaching reform, and *SCM Fundamentals and Interfacing Technology* is an important professional skills course for machinery major students. The current teaching model, which focuses on theoretical teaching supplemented by experimental teaching, has a large number of deficiencies in cultivating students to solve engineering problems. In the traditional SCM teaching method, teachers give lessons in the classroom according to the arranged chapter order of the textbooks. However, the examples cited in these textbooks are often too simple to meet real application needs. Even if a student has completed all the contents specified in the teaching plan, they may still be unable to systematically and thoroughly master the design and debugging of SCM application systems. Furthermore, the teaching order of most SCM courses basically involve the basic concepts, hardware structure, instruction system, assembly language, interrupt system, timer counter, serial port, memory extension, A/D and D/A interfaces, man-machine interface and application system design. As these knowledge points are learned independently, the students still cannot understand the complete SCM development process or the countless relations between each segment when the course is finished, and may even lack an understanding of the concepts of programmer and simulator. Therefore, it seems crucial to integrate the teaching content, arrange the teaching order and reasonably combine the contents of each segment, which is also key to solving the existing issues in the traditional teaching model. Nonetheless, this course has various new concepts with abstract content and precise logic, so it is difficult to be taught vividly in such a way that the students remain engaged. It is impossible to display the vivid features and strong control functions of SCM products through lectures alone. Therefore, the teaching of this course also challenges teachers in their theoretical knowledge, practical ability and teaching methods.

Over an extended period of teaching practice, based on the CDIO engineering education model (Bernhard, J., & Baillie, C. 2016), the author trained the students to acquire engineering application ability as the principal line; reconstructed the content of the course in accordance with the project module and used practical examples to organize unit teaching; and explained the basic knowledge and capabilities required for SCM application system design in the process of completing each example. These measures broke the constraints of the knowledge system, diverged from previous approaches and constructed a new teaching content system. Course experiments, individual projects, teamwork projects and other forms were also adopted to train the students to gain practical engineering capabilities.

## TEACHING OBJECTIVES OF COURSE AND IMPLEMENTATION MODEL

*SCM Fundamentals and Interfacing Technology* is an elementary course in professional skills for machinery majors. It not only requires the students to master the necessary professional knowledge and basic skills, but also trains them to consider independently and solve complicated engineering issues. Besides, the course aims to lead the students to understand the basic concepts of SCM hardware, software and interfacing design, then design an

application system according to real needs, allowing them to be trained to gain actual operational ability. The specific teaching targets of this course include.

### ***Teaching Target 1***

The students should master the relevant knowledge of SCM systems; understand the basic concepts, composition system and operating principle of SCM and extended chips; master the structure, principle, applications and related knowledge of SCM application systems; master programming methods using the assembly language; and write an SCM application program in the C language.

### ***Teaching Target 2***

The students should gain the capability to basically design an SCM application system and preliminarily solve complex engineering issues; complete the scheme design, circuit design, program design and system integration and debugging of SCM application systems; use computer-assisted digital circuit design and analysis software; and consider environmental protection, technical economy and other factors, thereby gaining the preliminary capability to solve complex engineering issues.

### ***Teaching Target 3***

The students should acquire and apply the criterion, specifications, handbook, atlas and related technical data; master the usage of key reference search tools and Internet search engines; utilize Internet and literature search tools to collect technical information on SCM-related issues and generate a literature summary report; gain knowledge of the development of new technology and concepts in SCM systems, and their future development directions; and be stimulated to pursue further study and research in this field so as to prepare for the subsequent course.

### ***Teaching Target 4***

The students should gain teamwork and technical communication capabilities; organize projects with team members and design an SCM application system; cooperate as a group to complete a mechanical system or piece of equipment with SCM as its main control unit; conduct market analysis and survey, overall scheme demonstration and design, mechanical structure design, SCM control system design, system assembly and debugging, technical economical analysis and other processes; and write a technical report and reporting draft, and perform project reporting and on-site system demonstration and response.

### ***Teaching Target 5***

The students should master the basic experimental methods for developing SCM, gain experimental research capabilities and obtain effective conclusions; through experimental operation and project learning, the students should acquire experimental study capability, master experimental research methods, gain experience in software programming and circuit design and debugging, summarize the content learned in a timely manner and finally obtain an effective experimental conclusion; and master the usage and experimental test methods of typical microprocessors, grasp how to debug the hardware circuits and software of microcomputer application systems, and obtain basic experimental skills in microcomputer application systems.

To achieve the above teaching targets, the following teaching methods and approaches are adopted: course teaching, assignments, discussions, quizzes, experimental research, group project and final exam. The details are shown in Table 1:

Table 1. Course teaching target realization matrix

| Teaching Target | Approach                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Target 1        | <ul style="list-style-type: none"> <li>• Classroom teaching: Highlight the focal points with clear thinking, pay attention to interaction between teacher and student, master the studying condition of the students and track each student in their learning process;</li> <li>• Discussion: Take the “Memory Extension” chapter as the content of the discussion sessions and train the students to conduct pre-class self-study, submit self-study reports, hold group discussions and communication, and master the teaching content;</li> <li>• Classroom tests: After teaching each technology point, spend 5–10 minutes on a quiz in order to evaluate and understand how much the students have mastered;</li> <li>• After-school assignments: Issue assignments after each class to enable the students to consolidate what they have learned, then correct all assignments and provide prompt feedback;</li> <li>• Final exam: At the end of the semester, check to what extent the students have mastered SCM-related knowledge and gained application capabilities through an exam comprising basic concepts (40%) and comprehensive application (60%).</li> </ul> |
| Target 2        | <ul style="list-style-type: none"> <li>• Large assignment: Through the post-class large assignment “SCM Development and Application Summary”, require each student to consult a wide range of literature, write a literature review and produce a PowerPoint presentation;</li> <li>• Experimental research: Complete eight credit hours and the preparation, experimental scheme design, experimental operation and writing of experimental reports for seven experiments;</li> <li>• Project teaching: Establish project groups consisting of 3–4 students. Students shall research the literature and technical data to complete the hardware design and software programming. Each group should complete one practical example of an SCM application system and write a project report.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                         |
| Target 3        | <ul style="list-style-type: none"> <li>• Large assignment: Through the post-class large assignment “SCM Development and Application Summary”, require each student to consult a wide range of literature and write a survey. Each group shall produce a PowerPoint presentation;</li> <li>• Project teaching: Establish project groups consisting of 3–4 students. Students shall research the literature and technical data to complete the hardware design and software programming. Each group should complete one practical example of an SCM application system and write a project report.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Target 4        | <ul style="list-style-type: none"> <li>• Project teaching: Establish project groups consisting of 3–4 students. Students shall research the literature and technical data to complete the hardware design and software programming. Each group should complete one practical example of an SCM application system, write a project report and reporting draft, and perform project reporting and on-site system demonstration and response.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |



|          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|          | Training in communications, lecture reporting and writing ability plays an important role in the entire project plan, which aims to train the students to use words and drawings accurately and proficiently according to the specifications in writing the technical reports, reporting drafts and statements.                                                                                                                                                                                                                                           |
| Target 5 | <ul style="list-style-type: none"> <li>• Experimental research: Complete eight credit hours and the preparation, experimental scheme design, experimental operation and writing of experimental reports for seven experiments;</li> <li>• Project teaching: Establish project groups consisting of 3–4 students. Students shall research the literature and technical data to complete the hardware design and software programming. Each group should complete one practical example of an SCM application system and write a project report.</li> </ul> |

## **COURSE TEACHING MODEL BASED ON CDIO ENGINEERING EDUCATION CONCEPT**

On basis of the CDIO engineering education concept (Cleginaldo Pereira de Carvalho 2016), the author introduced the state-of-the-art technologies of the discipline, followed education and teaching laws, and took training the students to solve engineering issues as the core. The *SCM Fundamentals and Interfacing Technologies* course adopts modular construction based on the work process so as to build a “Teaching, Learning & Doing” integrated task-driven teaching model that “takes the project tasks as the principle line and ensures that the course is teacher-dominant and student-oriented”. Finally, a feasible approach for improving the students’ practical ability was determined.

## **REFORM AND PRACTICE OF SCM TEACHING BASED ON CDIO ENGINEERING MODEL**

### ***Build a course modular teaching model determined by the typical work process of SCM application systems***

The author took training the students to gain engineering application ability as the principal line (Graham, R · 2018), reconstructed the course content in accordance with the project module, used practical examples to organize unit teaching and explained the basic knowledge and capabilities required for SCM application system design in the process of completing each example. These measures broke the constraints of the knowledge system, diverged from previous approaches organized and arranged according to the order of knowledge points, and rationally and scientifically constructed a teaching content system dependent on the need to explain the project knowledge points.

For example, in the process of learning the module “SCM Instruction System and Assembly Language Programming”, the students should accurately and properly use SCM instructions to interpret and write the program, rather than being able to recite the 111 SCM instructions. The teachers should further analyze and thoroughly explain several typical practical examples, then enable the students to firmly master the basic programming idea, approach and issues to be noted in the actual operating process.

According to the knowledge points in the work process of SCM application systems, it begins with deciding on a modular project (or task), then undergoes scheme demonstration, simulation verification, drawing and debugging (Fig. 1), and ends with the completion of the final product.

### ***Intensify practical teaching and reinforce training in engineering application and innovation capabilities***

As far as the practical teaching content and system reform are concerned, the practical teaching system was reconstructed according to the three major modules: experiment, design practice, and after-class technological activities. In light of the students' cognitive rules and the new training model and teaching content system, such practical projects as basic experiments, comprehensive experiments, virtual simulation experiments, large assignments, project design and after-class technological activities were established, forming an integrated practical system, as shown in Fig. 2.

### ***Establish the practice site and resources based on the CDIO teaching model***

Great efforts were made to construct high-level course teaching resources covering basic theory and application, texts and multimedia, and network courseware for use during and after class (Malmqvist, J., Wedel, M.K., Lundqvist, U., et al, 2019) . The three-dimensional high-level SCM course teaching resources were built with textbooks as the main body and supplemented by multimedia teaching courseware. An open SCM experimental system with proprietary intellectual property rights was also researched and produced. A practical teaching site equipped with 30 sets of new SCM development systems and 6 sets of SCM comprehensive experimental development systems under a network environment was constructed, as shown in Fig. 3.

### ***Write and publish a Proteus-based modular featured textbook and establish a virtual open experimental system***

The featured textbook introduces the basic knowledge of SCM and utilizes a series of modular practical example analyses and hands-on practices to enable the students to solve practical engineering problems by hand to a certain extent. At the same time, all circuits and code are brought into open, allowing the learners to study, research and carry out hands-on practice. In the textbook, Proteus, the latest development technology of the disciple, and the globally popular SCM development software Keil uVision4 are used as the development platform for building a virtual experimental system.

### ***Develop an “open-type SCM experimental system” with proprietary intellectual property rights***

New to China, the serial port programmable SCM STC89C52 was adopted by virtue of its convenient serial port programming, which greatly simplifies the development and time costs of SCM. The students can not only conduct replication experiments, but also build and test experimental circuits themselves in the design of new experiments, as shown in Fig. 4.

### ***Build a course learning website on SCM Fundamentals and Interfacing Technologies***

This course learning website includes the course overview (involving the course introduction, teaching programme, teaching plan, etc., giving the students a preliminary understanding of the course and its teaching process), network teaching plan, teaching videos, experimental guide, exercises, tests and other modules. This makes it possible to extend teaching and learning out of the classroom, intensify, expand and extend classroom teaching, and provide a platform for students' autonomous learning.

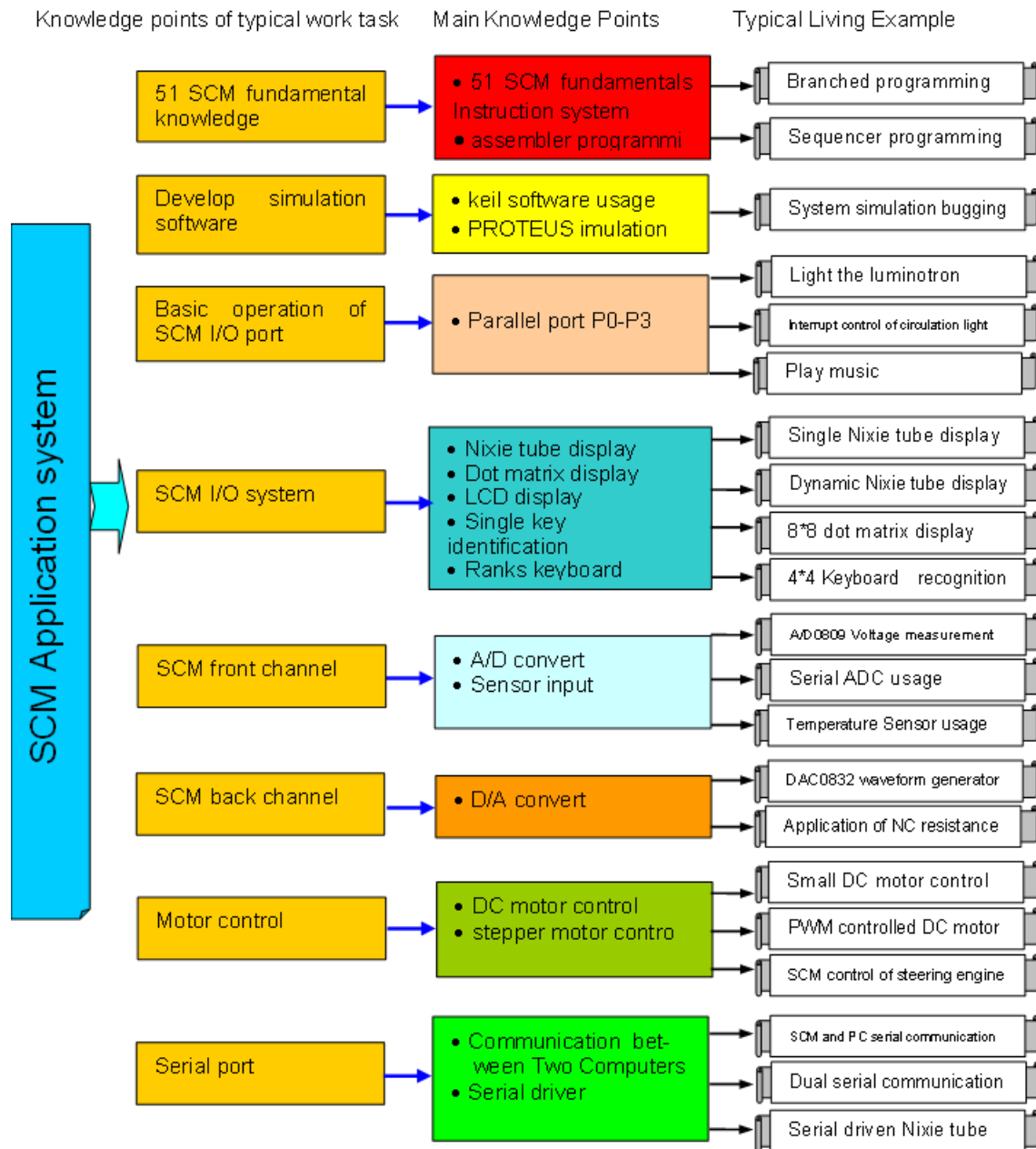


Figure 1. Course project modular

**Adopt a teaching model in which the course is “teacher-dominant and student-oriented”, and build a new “Teaching, Learning & Doing” integrated teaching approach**

During the teaching of this course, the teachers flexibly applied various kinds of teaching methods. When giving lectures, “project task” was taken as a principal line, and an approach was adopted which integrated teachers’ giving lectures with students’ explaining, individual questioning with group discussion, and classroom teaching with post-class communication, taking the advanced model of international CDIO engineering education as a reference (Li, X., Xing, Y. and Wang, H · 2021) . Through classroom lectures, symposia, short theses, comprehensive experiments and project training, heuristic and participative teaching was

implemented, which promoted the students to harmoniously develop their knowledge, ability and quality, and trained their innovative spirit, practical ability, self-study ability, communication ability, teamwork spirit and social adaption ability.

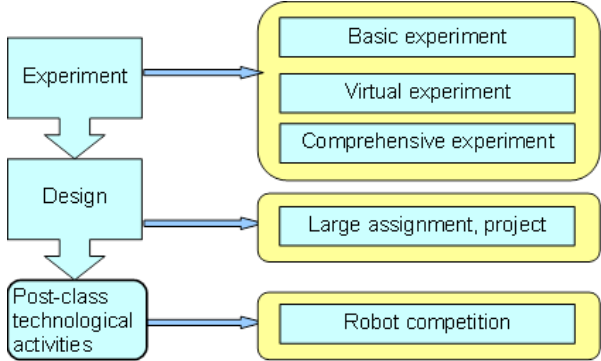


Figure 2. Practical teaching system for SCM securities



Figure 3. SCM course learning and practice site based on CDIO teaching model



Figure 4. Open-type SCM experimental system

The student-oriented concept was used to build the “Teaching, Learning & Doing” integrated task-driven teaching model. This model can be divided into three hierarchies, aiming to enable the students to proficiently master the project modular knowledge of typical work tasks based on the SCM application system. Hierarchy I refers to multimedia theoretical teaching and work task setup, and focuses on the teachers “Teaching” combined with the students explaining and discussing, as shown in Fig. 5. Hierarchy II refers to experimental teaching integrated with computer simulation training and hands-on practice to complete work tasks, and focuses on students “Learning”, as shown in Fig. 6. Hierarchy III refers to designing and producing, which means integrating project tasks and post-class technological activities to complete a mechanical system or piece of equipment with SCM as the main control unit. After conducting market analysis and survey, overall scheme demonstration and design, mechanical structure design, SCM control system design, system assembly and debugging, technical economical analysis and other processes, the students write technical reports and reporting drafts, and perform project reporting and on-site system demonstration and response. Via project learning based on the CDIO model, the students should understand that the development of SCM application systems is an iterative and constantly improved process. After ceaseless improvement in multiple links, a high-quality physical product will be completed as the final

product. In this hierarchy, it places emphasis on the students “Doing” in order to give full play to their subjective initiative and train their innovative and practical abilities.



Figure 5. Group discussion and explanation of students



Figure 6. The Students conduct system assembly and debugging

**Establish a formative evaluation approach that considers the students’ learning process**

After the course study is finished, in order to assess how well each student has mastered and applied each knowledge point, they shall be evaluated overall on the extent to which they have achieved the current course teaching targets through regular assignments, discussions, quizzes, experiments, individual reports, group reports, the final exam and other links. In the evaluation and examination of capability target achievements, the results of the final exam account for 50% and usual performance accounts for 50% (including with how much initiative the student participates in symposia, to what extent they focus on quizzes, how sensitive they are to new knowledge, how well they understand and apply new knowledge, what is their learning attitude reflected in post-class assignments and how deeply they consider and solve problems. Large assignments and symposia: 10%; experimental results: 10%; project learning: 30%). The detailed assessment and evaluation methods are shown in Table 2:

Table 2. Course teaching target evaluation matrix

| Composition of results | Assessment/evaluation links                                         | Grade | Assessment/evaluation rules                                                                                                                                                                |
|------------------------|---------------------------------------------------------------------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Usual results 50%      | Usual assignments (including large assignments and classroom tests) | 10    | Mainly check how well a student revises, understands and masters the knowledge points of each class, calculate the average credit of all assignments and record as 10% of total grade.     |
|                        | Experimental research                                               | 10    | Each time, give an independent score according to the experimental scoring criterion and dependent upon the reviewing conditions, scheme design, experimental operation and quality of the |

|                   |                  |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-------------------|------------------|----|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                   |                  |    | experimental report of each experiment for each student, then average the credits of all experiments and record as 10% of total grade.                                                                                                                                                                                                                                                                                                                    |
|                   | Project learning | 30 | Comprehensively evaluate the various abilities of each student according to the project learning scoring criterion and dependent upon the group project design report, system completion and debugging level, technical report and response conditions, and through the teachers' evaluation and group members' mutual assessment, then record as 30% of total grade.                                                                                     |
| Final exam<br>50% | Final exam       | 50 | The final exam shall be arranged according to the course teaching targets and grade hours. It shall mainly include 51 SCM fundamentals, numerical system conversion, instruction system and programming, memory expansion, timer/counter, interrupted application, parallel port application, man-machine interface, AD switch, DA switch and so on. The types of questions are divided between basic concepts (40%) and comprehensive application (60%). |

In project learning evaluation, the results of each group and group member are determined by mutual evaluation between members and the evaluation of the teacher, and according to the system completion and debugging level, group cooperation and communication conditions, technical reports, response conditions and other learning results. Training in communications, lecture reporting and writing ability plays an important role in the entire project plan, which aims to train the students to use words and drawings accurately and proficiently according to the specifications in writing the technical reports, reporting drafts and statements.

### ***Build a continuous course improvement mechanism which emphasizes feedback***

In the course teaching process, according to student feedback and the analysis of students' learning achievements, students are required to write an examination paper analysis, course summary and teaching reflections, and identify what could have been improved in the teaching of the course so as to make further improvements in the next teaching link.

## **CONCLUSION**

This topic is based on the work process of the SCM course modular teaching model. The practical system has been wholly practiced in machinery majors since 2010 and possesses a certain effect and high actual significance and promotional value.

Based on the CDIO engineering education concept, the teaching method of the course "takes the project tasks as the principle line and ensures that the course is teacher-dominant and student-oriented" and adopts the "Teaching, Learning & Doing" integrated task-driven teaching model to create a relaxed practical teaching environment.

The model introduced herein diverges from the evaluation method of the traditional teaching model and builds diversified evaluation methods based on mastering disciplinary knowledge.

The results of the above teaching practices verify that the students are significantly cultivated in developing SCM application systems, as well as in their practical and innovative engineering capabilities.

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# IMPLEMENTING CDIO STANDARDS THROUGH CHALLENGE-BASED LEARNING: A CASE STUDY IN AI ENGINEERING EDUCATION

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## ABSTRACT

We present our experience with Challenge-Based Learning (CBL) within an AI project in ESPRIT School of Engineering's 3rd and 4th-year AI engineering curriculum. Spanning two academic years, it examines how CBL, aligned with CDIO standards, melds practical skills and AI theory. The approach includes theoretical AI knowledge, hands-on AI application development, and integrates the UN's Sustainable Development Goals to promote a sense of global responsibility and ethical consciousness in our students. Additionally, CBL involves collaboration with local entities, enhancing students' real-world skills. The study highlights CBL's effectiveness in fostering teamwork, communication, intercultural awareness, and creativity. Initial feedback shows increased student engagement and a comprehensive understanding of AI's societal implications. The paper discusses CBL's role in meeting CDIO standards in AI education, enhancing technical and transversal competencies, and concludes with potential broader applications and future recommendations. This research adds to the dialogue on innovative AI and engineering education methods.

## KEYWORDS

Challenge-Based Learning (CBL), Artificial Intelligence Education, CDIO Standards, Sustainable Development Goals (SDGs) Integration. Standards 2, 3, 5, 7, 8, 9, and 11

## INTRODUCTION

This paper explores the implementation of Challenge-Based Learning (CBL) in AI engineering courses at ESPRIT School of Engineering, with a particular focus on the Conceive-Design-Implement-Operate (CDIO) Standards. CBL, as an experiential, student-centered approach, complements and enhances the CDIO framework, thus providing a comprehensive educational experience that combines technical skills with vital personal and interdisciplinary skills (Rådberg, 2020). The importance of CBL in AI engineering education lies in its ability to connect theoretical knowledge with practical applications, crucial for engineering programs. Studies such as Gudoniene et al. (2021) have emphasized the positive impact of CBL in engineering education, especially when aligned with Sustainable Development Goals (SDGs), providing both learning pathways and practical skills. Similarly, Crichton et al. (2022) found

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that interdisciplinary problem-based learning, akin to CBL, promotes increased awareness of diverse approaches and preparation for professional challenges in engineering students (Ikonen, 2009).

the adoption of CBL in AI engineering education, as illustrated in our case study at ESPRIT School of Engineering, signifies a substantial move towards preparing students for the multi-dimensional challenges of the future. This paper provides a detailed exploration of this approach, offering insights and guidelines for educators and institutions looking to enrich their engineering education programs.

## **MODULE OVERVIEW**

### ***Course Description***

This module, titled "AI Project for Community Impact", or shortly "AI Project", is integrated into the AI Engineering program targeting 3rd and 4th-year computer science students majoring in AI. Spanning 14 weeks with a 6-hour weekly commitment, the course adopts a Challenge-Based Learning (CBL) framework, guiding students through the Engage, Investigate, and Act phases. The curriculum is designed to deploy AI technologies to address real-world challenges that align with the United Nations Sustainable Development Goals (UN SDGs). Students work in teams to develop, implement, and refine AI solutions in collaboration with community or industrial partners, with a strong emphasis on ethical considerations and social impact.

### *Intended Learning Outcomes (ILOs)*

- **Develop AI Solutions:** Students will be able to design and implement AI models aimed at solving identified community challenges, applying appropriate AI tools and technologies.
- **Ethical Implementation:** Students will demonstrate the ability to incorporate ethical considerations and responsible AI practices throughout the development and deployment of AI solutions.
- **Engage Stakeholders:** Students will effectively collaborate with community and industry partners, ensuring the AI solutions are responsive to the needs and feedback of those partners.
- **Manage AI Projects:** Students will apply project management principles tailored to the lifecycle of AI development, ensuring timely and successful implementation of AI solutions.
- **Analyze Impact:** Students will assess the social impact of their AI solutions, evaluating their contribution towards achieving specific UN SDGs.
- **Communicate Outcomes:** Students will competently communicate both the process and outcomes of their AI projects to a broad audience, utilizing both oral presentations and written documentation.

## **SURVEY ANALYSIS:**

Our methodology for assessing the module incorporated a dual approach. Firstly, we documented weekly insights and remarks based on our supervision and leadership, focusing on the students' advancement and classroom interactions. Secondly, at the module's conclusion, we conducted a survey to gather broader feedback. The survey, completed by 28

of the 36 students in the class, was administered via Google Forms. It included a combination of Likert-scale and open-ended questions, allowing us to capture both quantitative and qualitative data on student experiences and perceptions.

**Quantitative analysis:**

Students rated various aspects of the program on a scale from 1 (worst evaluation) to 5 (best rating). These aspects include:

- Effectiveness of CBL in understanding and applying AI concepts.
- Helpfulness in developing skills for conceiving and designing AI solutions.
- Effectiveness in developing skills for implementing and operating AI solutions.
- Contribution of the program to the development of critical thinking and problem-solving skills.
- Overall satisfaction with the CBL approach in the program.

Table 1. summarizes the key statistical measures – mean and standard deviation - for each numerical question from the survey:

Table 1. The Key Statistical Measures – Mean and Standard Deviation

| Question                                                                | Mean | Standard Deviation |
|-------------------------------------------------------------------------|------|--------------------|
| Effectiveness in understanding and applying AI concepts                 | 4.19 | 0.75               |
| Developing skills in conceiving and designing AI solutions              | 4.24 | 0.62               |
| Developing skills for implementing and operating AI solutions           | 4.05 | 0.74               |
| Incorporation of ethical, societal, environmental, and economic aspects | 4.43 | 0.68               |
| Development in teamwork, communication, and leadership skills           | 4.48 | 0.60               |
| Enhancement in critical thinking and problem-solving                    | 4.48 | 0.60               |
| Engagement and involvement during the program                           | 4.33 | 0.73               |
| Preparation for understanding global challenges                         | 4.43 | 0.60               |
| Overall effectiveness of CBL in AI education                            | 4.14 | 0.73               |

Insights from the quantitative analysis:

- High Effectiveness in Teamwork, Communication, and Critical Thinking: The highest mean scores were observed in the development of teamwork, communication, and leadership skills (4.48) and enhancement in critical thinking and problem-solving (4.48). These scores suggest that the CBL approach is particularly effective in nurturing interpersonal skills and analytical abilities, which are crucial in modern AI education.
- Strong Incorporation of Broader Perspectives: The incorporation of ethical, societal, environmental, and economic aspects scored a high mean of 4.43, indicating that the CBL approach effectively integrates these essential perspectives into AI learning, aligning well with global educational trends and the CDIO Syllabus's emphasis on broader contextual understanding.

- **Good Engagement and Preparation for Global Challenges:** The program's ability to engage students and prepare them for understanding global challenges both received strong mean scores (4.33 and 4.43, respectively). This suggests that students felt actively involved and better equipped to tackle complex global issues through the program.
- **Slightly Lower Scores in Implementing and Operating Skills:** The lowest mean score was in developing skills for implementing and operating AI solutions (4.05). While still positive, this indicates a potential area for improvement, suggesting that the practical application and operation of AI solutions might require more focus in the CBL framework.
- **Variability in Responses:** The standard deviations, ranging from 0.60 to 0.75, reflect some variability in participant perceptions. This variability might be attributed to individual differences in learning styles, prior knowledge, or specific program implementations.

The quantitative data indicates a positive overall reception of the CBL approach in AI education, with particular strengths in promoting critical thinking, teamwork, and a broad understanding of societal and ethical implications. However, there appears to be room for enhancing aspects related to the practical implementation and operation of AI solutions, ensuring a better educational experience in line with the objectives of the CDIO Syllabus.

### ***Qualitative analysis***

In this analysis we include key themes and insights, supported by relevant quotes from the students.

#### *Overall Appreciation of the CBL Approach*

The first aspect of our qualitative analysis focuses on students' overall appreciation of the CBL approach.

- **General Sentiment:** The feedback indicates a strong endorsement of CBL's effectiveness in AI engineering education. Students appreciate the hands-on, practical nature of the approach, as evidenced by one student's remark: "I find the CBL approach in this program to be highly effective and engaging."
- **Engagement and Practical Learning:** The CBL approach is praised for its practicality and ability to engage students deeply in the subject matter. As another student notes, "The Challenge-Based Learning (CBL) approach is practically oriented, making learning more relatable."
- **Pros:**
  - **High Engagement:** Students are more engaged due to the practical, real-world applications of AI concepts.
  - **Effective Learning:** The approach facilitates a deeper understanding of AI, as it aligns well with the experiential learning style preferred by many engineering students.
- **Cons:**
  - **Potential for Overwhelm:** For some students, the intensity and hands-on nature of the CBL act phase might be overwhelming, especially for those who are accustomed to more traditional, structured learning environments.

### *Most Beneficial or Enjoyable Aspect of CBL*

This aspect examines what students found most rewarding about the CBL approach.

- **Real-World Relevance and Problem-Solving:** Many students cited the real-world relevance of the projects as the most beneficial aspect. One student expressed, "I found the real-world relevance and problem-solving focus of CBL most beneficial."
- **Freedom to Explore and Innovate:** The liberty to explore different avenues within AI and come up with innovative solutions is highly valued. A student highlighted this by saying, "I like the fact that CBL gives you the freedom to explore your ideas."
- **Pros:**
  - **Encourages Innovation:** Students are encouraged to think creatively and innovate, which is vital in the field of AI.
  - **Prepares for Real-World Challenges:** By dealing with real-world problems, students are better prepared for the challenges they will face in their professional lives.
- **Cons:**
  - **Lack of Guidance:** While freedom is appreciated, some students may feel lost without clear guidance, impacting the learning experience.

### *Challenges and Less Effective Aspects of CBL*

This item explores the challenges students faced with the CBL approach and aspects they found less effective.

- **Resource and Time Management:** Students encountered challenges related to resource availability and time constraints. One student noted, "While resources were provided, at times it felt like more could have been done to support our projects."
- **Securing Sponsorships and Partnerships:** Engaging with external entities like sponsors was a noted challenge. As one student shared, "Securing sponsors during the investigation phase was challenging and time-consuming."
- **Pros:**
  - **Real-World Problem Solving:** These challenges mimic real-world scenarios, preparing students for practical issues they might face in their careers.
  - **Learning Resourcefulness:** Dealing with resource constraints fosters creativity and resourcefulness.
- **Cons:**
  - **Overwhelming for Some Students:** The pressure to secure resources or sponsors can be overwhelming and detract from the learning experience.
  - **Time Compression:** The compressed timelines for certain phases, like the Act Phase, can limit the depth of exploration and learning.

### *Effectiveness in Raising Awareness about Global Challenges*

This aspect assesses how effectively the CBL approach raised students' awareness of global challenges.

- **Increased Awareness and Engagement:** Many students felt that CBL effectively raised awareness about global issues. A student expressed: "The CBL approach proved highly effective in raising my awareness about global challenges."
- **Pros:**
  - **Broadened Perspectives:** CBL helps students understand and appreciate the broader implications of AI technologies in a global context.

- Encourages Social Responsibility: Students are more likely to consider the societal and ethical dimensions of their work in AI.
- Cons:
  - Varied Impact on Awareness: The effectiveness in raising awareness may vary depending on the project's nature and the individual student's engagement level.

### *Suggestions for Improving the CBL Approach*

This part of our analysis focuses on students' suggestions for enhancing the CBL approach in AI Engineering education, based on their experiences and insights.

- Extended Time for Phases: Several students suggested extending the duration of certain CBL phases, particularly the act phase. One student mentioned, "maybe giving more time to the act phase would be beneficial."
- Efficient Time Distribution: The need for a more efficient distribution of time across all phases of CBL was highlighted. As one student advised, "Distribute the time efficiently across all phases of CBL."
- Complementary Classes: The idea of having complementary classes to bolster the CBL experience was proposed. A student suggested, "a complementary class to help us gain skills that are not covered in CBL would be helpful."
- Pros:
  - Enhanced Learning Experience: These suggestions aim to deepen the learning experience by allowing more time for exploration and reducing time-related pressures.
  - Comprehensive Skill Development: Complementary classes could provide a more rounded educational experience, covering areas not extensively addressed in CBL.
- Cons:
  - Potential for Overextension: Extending phases or adding complementary classes could lead to an overextended curriculum, possibly overwhelming students.
  - Resource Implications: Implementing these suggestions could require additional resources, including time and faculty involvement.

### *Synthesis of qualitative Findings:*

The analysis of the Challenge-Based Learning (CBL) approach in AI Engineering education provides a multifaceted view of its impact, challenges, and areas for improvement.

- Reception and Practical Application: The initial analysis highlights a highly positive reception of the CBL approach. Students value the practical, hands-on learning experience, which enhances engagement and deepens understanding of AI concepts. The opportunity to tackle real-world problems and the freedom to innovate are especially appreciated. However, there is a clear need for a balance between this freedom and structured guidance to cater to a diverse range of learning preferences. Ensuring this balance is crucial for maximizing the educational benefits of the CBL approach.
- Real-World Mimicry and Global Awareness: The approach is effective in mimicking real-world scenarios, fostering resourcefulness and practical skill development. Challenges such as resource constraints and time pressures are notable, with activities like securing sponsorships and managing project timelines offering practical experience but also proving overwhelming for some. CBL is successful in raising

awareness about global challenges, broadening students' perspectives, and encouraging social responsibility. However, the impact on global awareness varies among students, pointing to a need for more consistent integration of global challenges in CBL projects.

- **Enhancement Suggestions:** Students expressed a desire for an enhanced CBL experience that allows for deeper exploration and a more comprehensive skill set. Suggestions include extending certain phases and incorporating complementary classes, reflecting a need for a more balanced and holistic approach. While these suggestions aim to improve the learning experience, considerations regarding potential curriculum overextension and resource implications are crucial.

### *Overall Implications*

Combining all these insights, it is evident that while the CBL approach in AI Engineering education is highly valued for its practicality and real-world relevance, there are areas that require attention and refinement. Balancing freedom with structured guidance, consistently integrating global challenges, and carefully considering curriculum enhancements are key to advancing the effectiveness of the CBL approach. These findings offer a roadmap for us to refine and optimize CBL methodologies, ensuring that we can meet the diverse needs and learning styles of students in AI engineering programs.

## **ALIGNMENT OF CBL IN AI PROJECT MODULE WITH CDIO STANDARDS: AN EMPIRICAL ANALYSIS**

We examine in this section the alignment of an "AI project" module, conducted under the Challenge-Based Learning (CBL) pedagogical modality, with the Conceive-Design-Implement-Operate (CDIO) Standards. Through a mixed-methods approach involving the above quantitative surveys and qualitative feedback from students, the effectiveness of the CBL approach in an AI engineering context is evaluated against the CDIO framework. The findings reveal significant congruence with key CDIO Standards, notably in fostering teamwork, communication, critical thinking, and the integration of broader perspectives.

## **RESULTS AND DISCUSSION**

### ***Alignment with CDIO Standard 2 (Learning Outcomes)***

The CBL approach in the AI module demonstrated high effectiveness in developing interpersonal skills, including teamwork, communication, and leadership, with a mean score of 4.48. This aligns strongly with CDIO Standard 2, which emphasizes personal and professional skills and attributes. The focus on practical, real-world problem-solving under CBL resonates with the experiential learning style preferred in engineering education, enhancing a deep understanding of AI concepts.

### ***Alignment with CDIO Standard 3: Integrated Curriculum***

- **Technical and Non-Technical Integration:** The high scores in areas such as the incorporation of ethical, societal, environmental, and economic aspects (mean score: 4.43) suggest that the module successfully integrates non-technical considerations with

technical AI engineering education. This integration is a key component of CDIO Standard 3, which calls for an interdisciplinary curriculum.

- **Cohesive Learning Experience Across CDIO Spectrum:** The module's CBL approach, particularly effective in enhancing critical thinking and problem-solving skills (mean score: 4.48), indicates a curriculum that spans across the conceive and design phases effectively. However, the relatively lower score in implementing and operating AI solutions (mean score: 4.05) points to a potential gap in the 'Implement' and 'Operate' phases of the CDIO spectrum. This suggests a need for the curriculum to more robustly address these latter stages.
- **Student Feedback for Curriculum Enhancement:** Qualitative feedback highlighting the need for extended phases and additional resources indicates room for improvement in the curriculum structure. Aligning with CDIO Standard 3, the curriculum could benefit from adjustments that allow students to spend more time in each phase of the CDIO cycle, ensuring a more thorough and integrated learning experience.

### ***Congruence with CDIO Standard 7 (Integrated Learning Experiences)***

The AI module's emphasis on the application of ethical, societal, environmental, and economic aspects in AI solutions, scoring a mean of 4.43, reflects a robust alignment with CDIO Standard 7. This standard highlights the importance of integrated learning experiences that encompass a broad range of engineering and professional issues. The CBL modality effectively translates these aspects into tangible learning experiences, reinforcing students' ability to integrate diverse considerations in AI engineering.

### ***Areas for Enhancement: CDIO Standard 5 (Design-Implement Experiences)***

While the feedback for the module was generally positive, the slightly lower score of 4.05 in developing skills for implementing and operating AI solutions, though still high, was lesser compared to other criteria. This suggests an opportunity for enhancement in alignment with CDIO Standard 5, which emphasizes design-implement experiences. Strengthening this aspect of the CBL approach could further improve hands-on operational skills in AI engineering.

### ***Alignment of the "AI project" module with CDIO Standard 8: Active learning***

Based on the survey results we can derive these insights:

- **Student Engagement:** The module received a high mean score (4.33) for engagement and involvement, indicating strong alignment with CDIO Standard 8. This standard underscores the importance of active student participation and learning through doing, which the module seems to effectively foster.
- **Practical Learning Approach:** The emphasis on Challenge-Based Learning (CBL), as reflected in student feedback, aligns with active learning principles. Students' appreciation for the practical, hands-on nature of the module suggests that the learning experiences are well-aligned with the active engagement ethos of CDIO Standard 8.

### ***The alignment of the "AI project" module with CDIO Standard 9***

CDIO standard 9, which pertains to Enhancing Faculty Teaching Competence, can be analyzed in the context of the training sessions attended by the teacher supervisors for conducting Challenge-Based Learning (CBL).

- Faculty Training in CBL Methodology: The training sessions for teacher supervisors, focusing on the conduct of CBL, the roles of students and supervisors, and the intervention strategies, directly support CDIO Standard 9. This standard emphasizes the need for faculty to be well-prepared in pedagogical methods that facilitate active and experiential learning, which is central to CBL.
- Guidance and Intervention Strategies: The training on when and how teachers should intervene in the CBL process aligns with the aspect of CDIO Standard 9 that stresses the importance of faculty understanding their role in guiding and facilitating student learning, rather than directing it.
- Assessment Modalities of CBL: Faculty training on assessment modalities aligns with CDIO Standard 9's emphasis on faculty competence in evaluating student learning and progress. This is crucial in CBL, where assessment often involves evaluating complex, project-based activities.

### ***The alignment of the "AI project" module with CDIO Standard 11***

CDIO Standard 11 emphasizes assessing student learning in various areas including personal and interpersonal skills, product, process, system, and service building skills, as well as disciplinary knowledge.

- Effectiveness in Specific Areas: High mean scores in areas such as teamwork, communication, and critical thinking (4.48), and ethical and societal aspects (4.43) suggest effective assessment practices in these domains. However, the slightly lower score in implementing and operating AI solutions (4.05) indicates room for improvement in assessing these specific skills.
- Assessment of Personal and Interpersonal Skills: The high scores in areas related to personal and interpersonal skills demonstrate effective assessment methods in these domains, in line with CDIO Standard 11's emphasis on assessing a broad range of skills beyond just disciplinary knowledge.

The "AI project" module's assessment practices show good alignment with CDIO Standard 11, particularly in assessing a wide range of skills and using diverse assessment methods. However, the module could benefit from refining its assessment methods in the areas of implementing and operating AI solutions to fully realize the objectives of CDIO Standard 11.

### ***Student Feedback and Suggestions***

Qualitative feedback suggested extending certain phases of the CBL approach, aligning with CDIO Standard 3 (Integrated Curriculum). The suggestions to enhance learning experience and skill development reflect a need for a more balanced curriculum that thoroughly addresses the CDIO lifecycle phases.

## **DISCUSSION AND LEARNED LESSONS**

Our study on the Challenge-Based Learning (CBL) approach within the AI project module at ESPRIT School of Engineering demonstrates substantial alignment with key CDIO Standards. The methodology, involving a mix of quantitative surveys and qualitative feedback, revealed CBL's effectiveness in developing critical skills like teamwork, communication, and problem-solving, with notable success in integrating broader ethical and societal perspectives. However, the analysis also identified areas needing enhancement, particularly in the implementation and



operation of AI solutions, and in adapting to diverse student learning styles. These findings offer a roadmap for refining the CBL approach, highlighting the importance of balancing structured guidance with experiential learning, and ensuring a comprehensive curriculum that addresses all CDIO lifecycle phases. This study contributes to the discourse on innovative AI engineering education, providing insights for educators aiming to optimize CBL methodologies in line with CDIO standards.

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# **CULTIVATING LIFELONG LEARNING IN AI ENGINEERING: AN EXPERIENTIAL APPROACH THROUGH THE 'ARTICLE REVIEW' MODULE**

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## **ABSTRACT**

This paper details the 'Article Review' module, crafted for graduating AI engineering students to immerse themselves in and critically evaluate contemporary AI research literature. This module integrates several key CDIO standards, specifically focusing on integrated curriculum design (Standard 3), introduction to cutting-edge engineering challenges (Standard 2), and the promotion of active and self-directed learning (Standards 8 and 11), thereby developing a foundation for lifelong learning. The module employs diverse pedagogical approaches, incorporating rigorous critical reading, analytical writing, and persuasive oral presentation components. This trifold methodology ensures a comprehensive immersion into AI engineering research. Initial quantitative and qualitative evaluations from students indicate a marked improvement in their ability to critically analyze research papers, with a significant portion reporting enhanced interest in AI research. This communication aims to dissect the module's design intricacies, its operational dynamics in an academic setting, and its palpable impact on student learning outcomes. Furthermore, preliminary success indicators suggest that this module's framework could serve as a prototype for adaptation and implementation across various engineering disciplines, offering a viable model for how engineering education can integrate lifelong learning competencies.

## **KEYWORDS**

AI engineering education, Lifelong learning, Research paper review, Critical assessment, CDIO standards 2, 3, 4, 5, 7,8,11

## **INTRODUCTION**

The field of Artificial Intelligence (AI) is characterized by rapid and continuous evolution Raj (2023). This dynamic nature of AI poses a unique challenge to engineering education, particularly in preparing students for a landscape that demands current knowledge and the ability to engage in ongoing skill development. Addressing this challenge, this paper introduces the 'Article Review' module, a recent addition to the curriculum for graduating AI engineering students. The module is a response to the growing need for lifelong learning competencies in engineering education Broeck & al. (2022) and aligns with several key CDIO standards. The

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'Article Review' module draws on this educational trend, aiming to equip students with the ability to immerse themselves in and critically evaluate contemporary AI research literature. The module aligns with integrated curriculum design (CDIO Standard 2), introduces students to current engineering challenges (CDIO Standard 3), and promotes active and self-directed learning (CDIO Standards 8 and 11).

The approach adopted in this module is influenced by practices observed in various leading engineering schools globally. These schools have implemented diverse methods to promote lifelong learning skills, ranging from online and interdisciplinary programs to project-based and self-directed learning initiatives. The 'Article Review' module contributes to this spectrum of educational strategies by focusing on critical reading, analytical writing, and oral presentation skills in the context of AI engineering research.

This paper presents the design of the 'Article Review' module, exploring its implementation in an academic setting and its impact on student learning. The module immerses students in practical research and critical analysis of AI engineering research. Through a curated selection, students engage in deep reading, comprehension, and synthesis of complex technical content. Writing reviews and giving oral presentations improve their understanding of AI engineering principles and enhance essential analytical and communication skills, serving as valuable assets in both academic and professional pursuits. Initial student feedback indicates improvement in critical analysis abilities and a heightened interest in AI research. These findings suggest the module's potential as a practical tool for developing lifelong learning in engineering education, with its framework adaptable for implementation across various disciplines. This adaptability demonstrates the module's contribution to the broader goal of integrating lifelong learning competencies within engineering curricula.

## **LITERATURE REVIEW AND RELATED WORKS**

The integration of Lifelong Learning (LLL) within engineering education is crucial for educating engineers capable of adapting and innovating in a rapidly changing technological environment. This literature review examines the implementation of LLL, particularly through the Conceive-Design-Implement-Operate (CDIO) Syllabus and Standards. Dujardin et al. (2023) highlight a gap in engineering curricula regarding LLL competencies, such as developing learning plans and motivating continuous education. Their methodology suggests ways to embed these competencies into curricula. Van den Broeck et al. (2022) emphasize the necessity of LLL within discipline-specific contexts and support integrated curriculum design, aligning with CDIO Standard 2. Cicek et al. (2016) and Uziak et al. (2015) underline the significance of self-assessment and the educators' role in promoting LLL skills, in line with CDIO Standard 8. Further research by Puglisi and Domènech-Gil (2023), Nikolaenko et al. (2022), Marcynuk et al. (2020), and Ndubuisi et al. (2020) points to the effectiveness of LLL strategies and the deficiencies in preparing engineering students for lifelong learning, reflecting current educational demands.

Furthermore, engineering schools globally adopt various strategies to inculcate lifelong learning skills among students. Studies like that of Dawe et al. (2021) explore the integration of lifelong learning in Canadian engineering programs, revealing a preference for skills and knowledge over a deep commitment to lifelong learning. O'Neill et al. (2015) and Aleong and Strong (2015) discuss the importance of attributes such as continuous learning interest and self-regulation. Meanwhile, practical approaches like those outlined by Oviedo-Trespalacios et al. (2015) and the application of the Kern Entrepreneurship Education Network (KEEN) model,

as detailed by Santiago and Guo (2018), emphasize hands-on experiences and entrepreneurial mindset development. Additionally, initiatives like the Life Skills Course, John (2022) and the use of Bloom's Taxonomy and High Impact Practices (HIPs) Nizami et al. (2015) bridge academic learning with workplace demands through enhanced communication, teamwork, and independent learning capabilities.

## **“ARTICLE REVIEW” MODULE PRESENTATION**

In the context of adapting engineering education to the demands of a continuously evolving technological landscape, particularly within the field of Artificial Intelligence (AI), ESPRIT School of Engineering has developed and implemented a novel module titled "Article Review." This initiative, part of the AI Engineering specialization, aims to bridge the gap between academic learning and the practical challenges encountered by engineers in the AI sector.

### ***Module Overview***

The "Article Review" module is specifically designed to introduce graduating engineering students to advanced research in the field of AI. Through a structured framework, students are required to select, analyze, and present findings from selected leading research papers in AI engineering. The module spans three weeks, under the guidance of an Instructor, targeting students in the fifth and terminal year AI class.

### ***Objectives***

The primary objectives of the module are fourfold:

1. Introduce students to contemporary research and developments in AI engineering.
2. Enhance students' abilities to critically read and understand scientific literature.
3. Cultivate skills necessary for the synthesis and communication of complex technical data.
4. Embed a culture of lifelong learning, highlighting the importance of continual knowledge acquisition beyond formal education.

### ***Intended Learning Outcomes of the module***

Upon completion, students are expected to demonstrate a comprehensive ability to:

1. Analyze and interpret methodologies, results, and implications from selected AI research, understanding their relevance to both academic and practical applications.
2. Construct detailed reviews that encapsulate the core aspects of the research, including its significance, methodologies, findings, and broader implications for the field of AI.
3. Effectively communicate research insights to a broad audience, articulating the relevance and applications of the findings in AI engineering.
4. Critique and evaluate research works, assessing their contribution to the field.
5. Adopt a lifelong learning approach, actively seeking out and integrating new knowledge in their professional practices.

### ***Evaluation***

Student performance in the module is assessed through a combination of written reviews (60%) and oral presentations (40%). The evaluation criteria focus on the students'

comprehension, analytical skills, and the ability to engage with and convey complex ideas effectively.

### ***Pedagogical Approach***

The module employs a comprehensive template and structure for both the written review and oral presentation, guiding students through the critical analysis of research papers. This approach facilitates the deep understanding of AI technologies and methodologies and encourages students to reflect on the significance and future prospects of the research.

## **IMPLEMENTATION OF THE 'ARTICLE REVIEW' MODULE WITH RELEVANT CDIO STANDARDS V3.0**

### ***Overview***

The 'Article Review' module in AI engineering education aligns with key CDIO Standards 3.0, focusing on those most relevant to its goals and structure. This analysis outlines how the module implements these specific standards, demonstrating its integration into the CDIO framework.

### ***Alignment With Selected CDIO Standards***

**Standard 2 - Learning Outcomes:** The 'Article Review' module directly targets learning outcomes that include critical analysis, understanding of AI technologies, and ethical considerations. These outcomes align with the CDIO's emphasis on personal, professional, and product-process system building skills.

**Standard 3 - Integrated Curriculum:** The module integrates technical knowledge of AI with critical thinking and research analysis skills. This curriculum design aligns with the CDIO's principle of intertwining disciplinary knowledge with personal and interpersonal skills.

**Standard 7 - Integrated Learning Experiences:** The module provides an integrated learning experience by combining the study of AI research with the development of critical and analytical skills. This approach reflects the CDIO's emphasis on incorporating professional engineering issues into learning experiences.

**Standard 8 - Active Learning:** Active learning is a core component of the module, as students are engaged in critical thinking and problem-solving activities related to AI research literature. This methodology aligns with the CDIO's focus on active and experiential learning methods.

**Standard 11 - Learning Assessment:** The module's assessment methods are diverse, including analysis, presentations, and discussions. These methods are in line with the CDIO's approach to evaluating a broad range of learning outcomes, from technical knowledge to personal and interpersonal skills.

## **ALIGNMENT WITH THE CDIO SYLLABUS THROUGH THE 'ARTICLE REVIEW' MODULE**

### **Overview**

The 'Article Review' module in AI engineering education is designed to target specific competencies outlined in the CDIO Syllabus. This section examines how the module addresses these competencies, reinforcing its role in developing a comprehensive skill set in students.

### ***Aligning with Key Competencies in the CDIO Syllabus***

#### *Technical Knowledge and Reasoning (Section 1):*

Knowledge of Underlying Sciences (1.1): Through the analysis and evaluation of AI research literature, students indirectly engage with the underlying scientific principles that form the basis of AI technologies. This includes areas like mathematics, statistics, and computer science, which are fundamental to understanding and evaluating AI algorithms and systems.

Core Engineering Fundamental Knowledge (1.2): The module requires students to have a foundational understanding of core engineering concepts relevant to AI. This includes basic knowledge of computing systems, software engineering, and algorithmic principles, which are necessary for comprehending and critiquing the AI research articles.

Advanced Engineering Fundamental Knowledge (1.3): AI engineering is a rapidly advancing field, and the 'Article Review' module exposes students to advanced topics through contemporary research papers. This includes emerging AI technologies, machine learning algorithms, data analytics, and their applications. Engaging with these advanced topics enhances the students' understanding of the cutting-edge developments in AI engineering.

#### *Personal and Professional Skills and Attitudes (Section 2):*

Systems Thinking (2.3): The module encourages students to approach AI technologies from a systems perspective, considering the interplay between technical and human elements. This aligns with the expanded view of systems thinking in the CDIO Syllabus.

#### *Adaptability and Flexibility (2.4.3):*

Students engage with rapidly evolving AI technologies, supporting adaptability and resourcefulness, crucial in the dynamic field of AI.

#### *Lifelong Learning (2.4.7):*

The module's focus on continuous engagement with current research in AI encourages the development of learning agility, aligning with the Syllabus's emphasis on lifelong learning.

#### *Interpersonal Skills (Section 3):*

Collaboration (3.1.2) and Stakeholder Engagement (3.1.3): Analyzing AI research within the module often requires understanding diverse perspectives, which promotes skills in multi-perspective collaboration and stakeholder engagement.

*Conceiving, Designing, Implementing, and Operating Systems in a Societal Context (Section 4):*

Societal and Environmental Context (4.1): Students are exposed to the societal and environmental implications of AI technologies, developing an understanding of the broader impact of engineering work.

Systems Engineering and Management (4.3): The module's focus on AI research includes aspects of conceiving and understanding system requirements and goals, which aligns with the Syllabus's focus on systems engineering and management.

Designing for Sustainability (4.4): By engaging with research on sustainable AI solutions, students develop an understanding of sustainable design practices.

*Expansion (Section 5):*

Research (5.3): The module develops research-related skills by engaging students in the analysis and evaluation of AI research, aligning with the Syllabus's new focus on research competencies.

## **ASSESSING THE IMPACT OF THE 'ARTICLE REVIEW' MODULE ON LLL SKILLS**

### ***Quantitative and Qualitative Analysis of Student Feedback***

This section presents a comprehensive analysis of student feedback from the 'Article Review' module, which was designed to enhance lifelong learning skills among AI engineering students. The analysis integrates both quantitative and qualitative data collected from a questionnaire completed by 36 students who participated in the course.

#### *Quantitative Analysis: Insights from Likert Scale Responses*

The quantitative component of the feedback involved Likert scale questions, focusing on various aspects of the course. This part of the analysis provides valuable insights into the module's effectiveness, its strengths, and areas for improvement.

Response Rate and General Observations: Out of 36 students, responses were received from 21. The Likert scale, ranging from 1 to 5, was used to gauge students' perceptions, with higher scores indicating more positive feedback.

Table 1: Summary of Quantitative Responses

| Question                                                                                | Mean | Standard Deviation |
|-----------------------------------------------------------------------------------------|------|--------------------|
| The course effectively introduced me to cutting-edge research in AI engineering.        | 4.71 | 0.46               |
| I feel more aware of current research methodologies in AI after completing this module. | 4.33 | 0.66               |
| The curated list of research papers was diverse and relevant to AI engineering.         | 4.62 | 0.5                |
| The course structure facilitated deep comprehension of the selected research papers.    | 4.19 | 0.75               |
| I felt encouraged to think critically about the papers reviewed.                        | 4.48 | 0.51               |



|                                                                                                   |      |      |
|---------------------------------------------------------------------------------------------------|------|------|
| I felt adequately prepared to synthesize the content of the articles into a coherent review.      | 3.95 | 0.74 |
| The guidelines for the oral presentation were clear and helpful.                                  | 4.71 | 0.46 |
| The module enhanced my lifelong learning skills.                                                  | 4.43 | 0.68 |
| The evaluation criteria for the written review were clear and fair.                               | 4.67 | 0.58 |
| The module fostered a culture of lifelong learning in AI.                                         | 4.33 | 0.66 |
| I feel more confident in my ability to critically evaluate research papers.                       | 4.1  | 0.62 |
| My skills in presenting complex technical information have improved.                              | 4.19 | 0.81 |
| I believe I have enhanced my ability to understand and analyze complex research studies.          | 4.19 | 0.68 |
| The balance between understanding, analyzing, and critiquing the papers was appropriate.          | 4.14 | 0.65 |
| The curriculum design facilitated a holistic understanding of the subject matter.                 | 4.1  | 0.7  |
| The module effectively integrated different skills (e.g., reading, analysis, presentation).       | 4.67 | 0.48 |
| The module provided a clear introduction to the field of AI engineering research.                 | 4.43 | 0.6  |
| The curated list of research papers effectively covered the key areas of AI engineering.          | 4.48 | 0.68 |
| The "Article Review" module enhanced my perspective on AI engineering.                            | 4.48 | 0.51 |
| The module encouraged active engagement with the content.                                         | 4.48 | 0.51 |
| Writing reviews and giving presentations made me more comfortable with public speaking.           | 4.62 | 0.59 |
| The active learning components (e.g., discussions, presentations) were valuable.                  | 4.24 | 0.7  |
| The module has made me more inclined to continue researching in AI engineering.                   | 4.62 | 0.5  |
| I feel equipped with the skills to continue learning in the field of AI engineering.              | 4.38 | 0.67 |
| The emphasis on fostering a culture of lifelong learning in AI was evident throughout the module. | 4.29 | 0.64 |

The quantitative questionnaire results provide a comprehensive view of the students' feedback on various aspects of the "Article Review" course. The mean scores across all questions range from 3.95 to 4.71, indicating an overall positive reception of the course components and outcomes. The lowest mean score relates to students' readiness to synthesize the content of articles into coherent reviews, suggesting an area for potential improvement. The highest mean scores are attributed to the effectiveness of the course in introducing cutting-edge research in AI engineering, the clarity of the guidelines for oral presentations, and the integration of different skills throughout the module, each with a mean score of 4.71. Standard deviation values range from 0.46 to 0.81, with most questions having a standard deviation below 0.70, suggesting a relatively consistent agreement among participants. The presence of minimum scores at or above the midpoint for all questions highlights a generally positive baseline evaluation. However, the variability indicated by standard deviation values, particularly in questions related to students' skills and preparedness, suggests areas where experiences and perceptions may vary more significantly among participants.

Table 2: Themes from Qualitative Responses

| Questions                                                                                              | Key Themes                                                                                                                                                                                            |
|--------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Which aspects of the module did you find most valuable?                                                | <ul style="list-style-type: none"> <li>- Technical aspects and practical applications</li> <li>- Diversity and relevance of articles</li> <li>- Continuous engagement and understanding</li> </ul>    |
| What improvements would you suggest for future iterations of the "Article Review" module?              | <ul style="list-style-type: none"> <li>- Keep articles list updated</li> <li>- Incorporate more practical validations</li> <li>- Include projects for applying concepts</li> </ul>                    |
| How would you describe the overall relevance of this module in the context of AI engineering research? | <ul style="list-style-type: none"> <li>- Enhances familiarity with research methodologies</li> <li>- Improves critical thinking and academic growth</li> <li>- Relevant and timely content</li> </ul> |

The integrated analysis of both quantitative and qualitative feedback from the 'Article Review' module participants reveals a generally positive reception of the course's effectiveness in developing lifelong learning skills. The quantitative data points to the module's strengths in introducing students to contemporary AI research and its relevance. The qualitative responses, while affirming these strengths, also highlight areas for improvement, particularly in enhancing practical application and providing structured learning support. This feedback is very useful for refining the module in future iterations.

## CONCLUSION

The 'Article Review' module at ESPRIT School of Engineering, by engaging AI engineering students with cutting-edge AI research, has effectively contributed to enhancing their analytical, synthesis, and communication skills. This module serves as a link between rapid advancements in AI and innovative educational practices, promoting a mindset of adaptability and continuous learning essential for future engineers. Integrating practical projects, where students implement and test ideas from reviewed articles, could deepen their grasp of the content. To ensure the module remains relevant and effective amid the rapidly evolving AI field, it is crucial to continually evaluate and update its content and approach. Broadening the module's scope to include other engineering disciplines could extend the principles of lifelong learning, in line with CDIO Standard 1 (Context). Conducting longitudinal studies to assess the module's impact on graduates' careers and lifelong learning aligns with CDIO Standard 11 (Learning Assessment), providing insights for its ongoing enhancement. Incorporating practical projects for students to test and apply concepts from AI research articles significantly enriches their learning. This hands-on approach could improve comprehension of the studied materials and prepares students for real-world challenges, embodying the essence of the CDIO approach by integrating conception, design, implementation, and operation into the learning process.

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# IMPLEMENTING AI-DRIVEN TOOLS IN UX DESIGN COURSE IN ENGINEERING AND BUSINESS EDUCATION

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## ABSTRACT

Pedagogical transformations aim to improve the learning process. These innovations in training/teaching methods are crucial within the evolving economic landscape and technological advancements. Previous work on design thinking for CDIO curriculum development demonstrated that learning experience in a multi-disciplinary environment and human-centric approach help students learn in an innovative process. This article is about UX Design, which is also a user-centered process, but which focuses on optimizing the user experience when using technological products. The aim of our endeavour is to implement AI tools in UX design taught to engineering and business students at Esprit, allowing them to be immersed in the realm of industry 4.0. Incorporating AI tools into user research methods during the UX design process in our curricula not only optimized the acquisition of essential data for students, but also fostered their skills in data analysis. In addition, it allows teachers to level up the complexity of the designed learning outcomes. In this regard, we explore how effective and engaging pedagogical methods using AI-driven tools could be in engineering and business education. Indeed, our programs are aligned with CDIO syllabus, we aim to cultivate a multifaceted skill set, covering knowledge, attitude, and skills development. Moreover, the utilization of AI promotes a positive attitude toward embracing technological advancements, encouraging adaptability and a forward-thinking mindset. In terms of skills, students sharpen their strategic product design abilities, honing a crucial competence in navigating the intersection of AI technology and human-centered design practices. To illustrate this, we present a case study showcasing how the integration of AI tools in our curriculum has enabled students to navigate complex challenges effectively and teachers to update learning outcomes for enriched learning experience. Moreover, we examine the impact of these pedagogical transformations and AI integration, in conjunction within the CDIO context in our programs. We also share our survey findings to reinforce the efficacy of our approach showing that it could be adopted in different fields. We conclude by drawing up a reflective practice process to ensure an insightful integration of innovative tools into curriculum design helping our students to address their needs in a dynamic technological landscape.

## KEYWORDS

Human-Centric Design, AI-driven pedagogical approach, Lifelong learning, CDIO standards 3.0, Standards: 1, 2, 5, 8.

## **INTRODUCTION**

The dynamic evolution of the economic landscape and the advances in technology have led companies to rethink their design, production methods and, training of employers and employees (Gajek, et al, 2022). The increasing use of digital interaction is one of the reasons behind the major role assigned to UX Design (Zhong, Z. & Balagué, C. 2021). Digital interfaces are omnipresent in our daily lives, not only in the on-screen world, but also in our free time, social relationships and professional activities. The emergence of artificial intelligence, virtual reality, voice assistants and other uses are new challenges for UX Design. A study by Gomez entitled why web performance matters (2011) reported that 88% of users are not inclined to re-visit a website if their experience was unsatisfactory and 70% of online business fails because of a negative user experience. These statistics alone sum up the importance of UX. The educational landscape is evolving, and we must implement fresh methods in our education systems allowing our students, as a future employee 4.0, to be adapted to a digitalized work environment (Alcacer and Cruz-Machado, 2019).

In this paper, we'll start by defining the UX Design process and integrating it into the CDIO Model as a tool for continuous improvement (Crawley et al, 2014). We'll then proceed with a case study of the UX Design Module in the two schools Esprit Engineering and Esprit Business, to explore the approach and interest of implementing this UX Design process, as well as explaining how we've integrated AI tools to involve students in technological trends. We will show the impact of these AI tools on learning outcomes by comparing the evolution of the module sheets and the evaluation grid reflecting the relevance (Evaluation groups regularly review and revise program learning outcomes, based on changes in stakeholder needs in CDIO standard 2). Finally, we'll discuss the results of our student feedback survey.

## **UX DESIGN AND EDUCATION ENGINEERING**

Design, according to Archer and Layton, is a complex process driven by different needs and values, important in both practical and conceptual aspects. Leonardo da Vinci's constructivist approach, rooted in experimentation and reasoning approach emphasizes the importance of engineering and scientific advancement. This approach highlights the significance of creative thinking, adaptability, and analysis in tackling complicated problems (Capra, 2007, p. 161). Aligning with this philosophy, UX Design combines user experience principles with a problem-solving mindset, pioneered by the Co-Founder of Nielsen Norman Group.

Don Norman and defined by Jean-François Nogier, the President of Usabilis, UX consulting and digital ergonomics company. It goes beyond traditional linear thinking and encourages a holistic, interdisciplinary perspective in creating solutions that meet user needs. In educational settings, UX Design promotes interdisciplinary thinking and iterative problem-solving, motivating students to engage in a continuous dialogue between generating ideas and taking action. By prioritizing human-centred design, students develop empathy and gain a deeper understanding of real-world issues, resulting in more effective and meaningful solutions. Therefore, UX Design serves as a versatile approach that fosters innovation and addresses the complexities of modern challenges across different fields.

## UX DESIGN VERSUS CDIO MODEL

The design process follows the Double Diamond model (G. Daniel, 2019), was produced as “a simple graphical way of describing the design process” (Design Council, 2007). Consisting of four phases: Discover, Define, Develop, and Deliver. Although the double-diamond visual is supposed to be common to all projects, the design council suggests modifying (or customizing) it to meet the needs of each project. As mentioned in the visual Figure 1 based on the different stages outlined in the UX Design course, which will be examined in the case study section. The Double Diamond model is not linear, but encourages us to think in a dialectical way, to better define the problem and find more complete solutions.

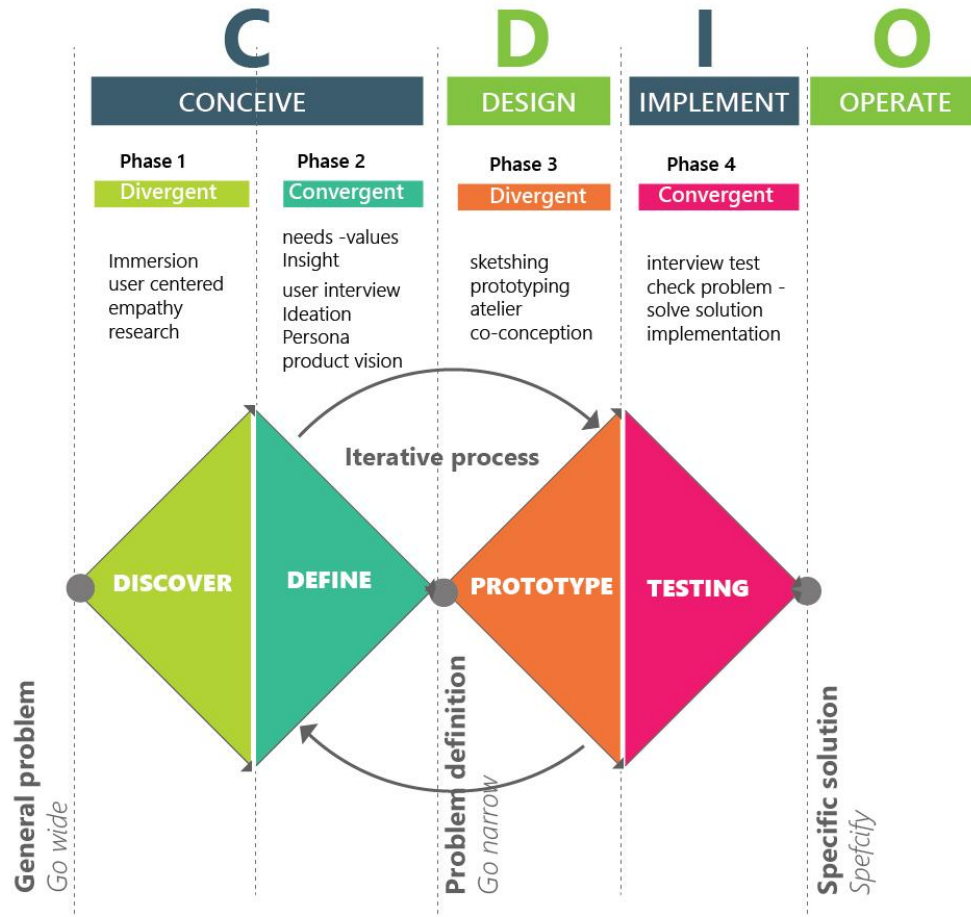


Figure.1 Integrated double diamond on CDIO models

This illustration underlines the importance of embedding the UX Design process as a teaching and active learning method for engineers to address complex human-centered problems by understanding user needs (Discover), reframing and defining the problem, identifying the user (Define), generating ideas, developing a prototype/solution and finally testing and iterating even after the implementation phase, since it's an iterative process that always adapts to socio-economic changes. Users expect continuous progress, improvements, innovations and updates.

We'll start by presenting the different phases of the UX Design process and then explaining how it can be integrated into the CDIO model.

### ***Process UX Design***

First Diamond: to explore the problem and identify the real user and his needs. It is structured in two phases:

- A general divergent phase to generate goals and assumptions. By investigating and immersing ourselves in user situations, we can then put forward a real value proposition. In this discover phase, a fundamental study, including an audit of the existing situation and competitive benchmarking, allows to establish design-oriented hypotheses for the project. Qualitative research is crucial, involving interviews with the intended users, where we inquire about their thoughts and reasons to enhance our comprehension of their product vision.
- The second phase, define, focused on research and analysis. It is more specific, because it converges on a synthesis and reframing of the need, which is the result of an analysis of user data to confront the brief, expectations and build a "real" and solid solution.

Second Diamond: design solutions until they are achieved. It is also divided into two phases: once the need is defined, the second Diamond is used to build the user experience:

- A first phase to generate ideas for functionalities, based on the user needs identified in the previous phase. This is followed by the setting up an information architecture through the development of the prototype. The purpose of this phase is to produce a user scenario by prototyping the user's journey through a low-fidelity screen level, while considering ergonomics.
- The second phase converges and becomes increasingly specific, measuring the success of the user journey by testing and iterating. These tests highlight the corrections that need to be made to the prototype.

### ***Integrate Model CDIO***

The UX Design process can be integrated with the conceive-design-implement-operate (CDIO) framework standard 1 to develop personal skills together with inter-personal skills shown in Figure1.

*Conceive:* In the CDIO model, C refers to defining the customer's needs, while taking into account the project context in terms of technological and strategic choices. It corresponds to the first diamond in the process UX Design based on empathy, which mean putting ourselves in the user's shoes, to define real complex problems and reframe the project context.

*Design:* D of the CDIO initiative is combined with the prototyping phase, enabling the practical design of prototypes from Low Fidelity to High Fidelity. In order to achieve this improved, advanced prototype in the UX Design process, the different prototype test phases are essential.

*Implement:* is the transformation of design into product, including manufacturing, coding, testing and validation. This is a fundamental phase in the project cycle. In the UX Design, once



the prototyping stage is complete, the next step is to create and test the functionalities and interfaces.

*Operate:* One of the CDIO initiatives focuses on maintaining the product and making it evolve on an ongoing basis. This is part of the UX design process after the testing phase. As we've mentioned, this process is based on iteration and user feedback. But it's also a human-centered process, with users' needs and expectations evolving within the economic and technology environment standard 5. Therefore, we believe that an enduring product, along with its implementation and continuous improvement based on user feedback, plays a crucial role in UX design.

## **UX DESIGN IN ENGINEERING EDUCATION: STUDY CASE ESPRIT SCHOOL OF ENGINEERING**

In the Academic Year of 2019-2020, a course was developed for the 5th year of the TWIN (Web and Internet technology) Option program. The course was designed for 80 students and provided 100% in-class training. It all began when Esprit was partnered with Google and held the first Google MENA Masterclass UX Design Thinking event at Esprit. Afterwards, we participated in the workshop "Design Thinking: a pedagogy at the disposal of the trainer". In the context of pedagogical conferences by CRP (Pedagogical Resource Center). Our conviction stems from the belief that adopting a transdisciplinary approach aligns with the preparation of future engineers. This fact was also confirmed during multiple meetings with startups in the program "Google for startups Accelerator" and the "Design Lab". Indeed, UXD is more and more related to all innovation programs, where the whole of the students, whatever their university course or work experience, join this program to learn or rediscover how to conceive solutions to all sorts of issues. Even more accentuated by the fact that we meet groups of our Esprit students in the UX Design Thinking by Google Masterclasses, who are there to enhance their projects. The course has grown over the last years reaching a total of more than 300 students in AY 23-24, organized into two options: 4 classes of SIM (Mobile Information System) option and 6 classes of TWIN (Web and Internet technology) option. It should also be noted that it has been integrated with the two courses of the SIM option which are the MHA (Mobile Hardware Application) and MVision (Mobile vision) courses.

### ***Embracing the AI era by Implementing AI-driven tools in the UX Design course***

The COVID context led us to migrate to online teaching platforms. However, this was not the only change for us. All 5th year level options have moved to 80% online learning.

As we are currently working with a user-centered approach to training, it is appropriate to apply this approach to the development of the course's pedagogical content. Indeed, we asked our 5th year TWIN students to share their feedback on this course. As a result, we refined the teaching material by taking into consideration the feedback of our users. Among the recommendations, the students favor the integration of a digital tool in the User Research section of our course content. In this regard, through the PFE (Final Year Engineering Projects) project of our student, we have benefited from an AI UX Research platform; a tool to facilitate the assessment of user studies and highlight their findings. This allowed us to work online and in a collaborative way but also to improve our learning materials and adapted it to our 5th year students.

### ***AI-driven tools in UX Design: Added Value***

The integration of AI tools in engineering and business education for UX Design courses is significant as it bridges the gap between theoretical knowledge and practical application.

The nextapp.co platform (Figure 3) is an AI-powered user discovery tool that reduces research time and effort through automatic audio and video transcription and analysis. Its features enable students to understand how real customer evidence informs design decisions and democratizes UX research. Teaching UX Design with AI-driven tools allows students to learn the essentials of the UX process in a format that mimics real-world scenarios.

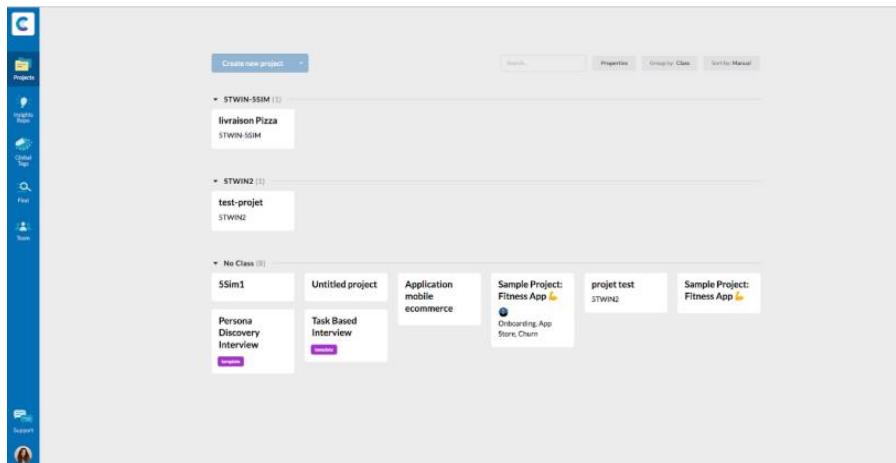


Figure 2. Examples of projects on the Considerly platform.

Considerly (Figure 2) is a Survey Data platform (qualitative and quantitative) that allows us to: Evaluate what, why, how: we collected data to identify our users via interviews in the form of voice recordings and then integrate them into the platform. Classify the needs and problems of users: through the creation of tags (data analysis). Organize the needs and problems in order of importance through the conclusions we drew from the tags.

This digital tool based on AI has allowed us to build a common database of information, to learn new ways of collaborating and to develop our projects according to a process based on UX Research methods. We are carrying on with the experience in the current academic year, AY 22/23, by moving to a new UX platform. This upgrade has allowed us to deepen more in the User research of qualitative studies but also to work on "Esprit university" pro version.

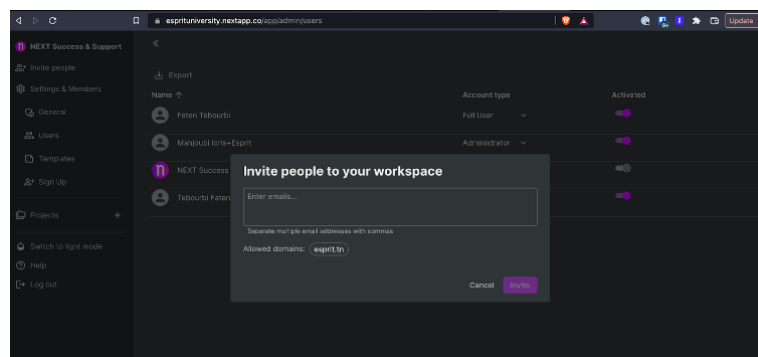


Figure 3. Example of student's project on the Nextapp platform.

For the AY 23-24, we incorporated a new AI platform that supports Timestamp-assisted key meeting moments (Figure 4). The AI Meeting note-taker instantly summarizes key moments,

making us focus on talking rather than note-taking. The platform is also equipped with AI Meeting transcription, which translates the content and records it, enabling us to read the conversation and review key moments. We can also arrange this data by tagging videos and creating a clip of multiple interview sequences to match a specific theme or need.

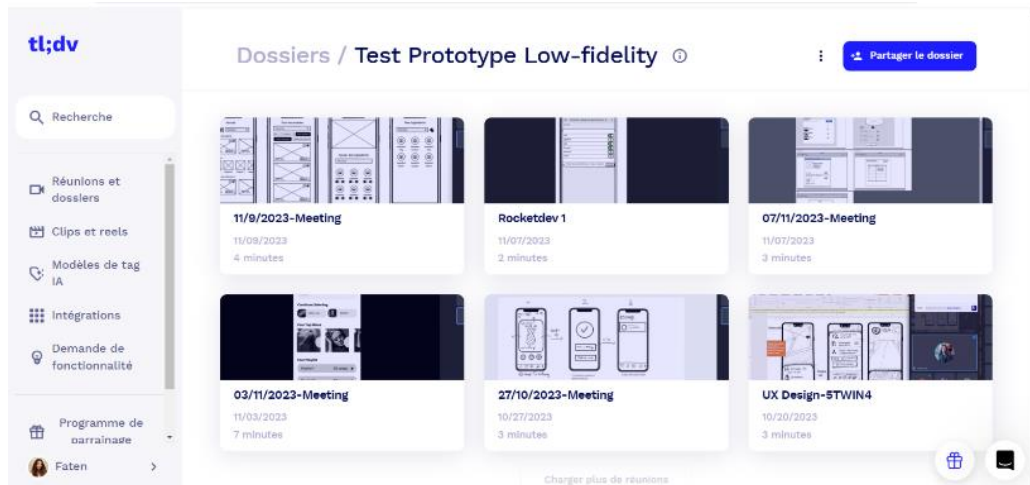


Figure 4. Example of students' project on the tldv platform.

### **Steps of the UX Design course**

The UX Design course lasts for 7 weeks, with 80% of it being online and 20% in person. The final week is dedicated for project presentations and outcomes.

#### *First step: Immersion and exploration*

Which involves researching and exploring the project's sociological, economic, technological, and artistic contexts. Methods used include competitive research and qualitative research through user interviews. Students will gather data for their research project and use AI Transcription to automatically transcribe mp4 audio into a file. The first stage involves sorting and organizing the raw data. In the second stage, the students will analyze the data by creating tags, which is referred to as the "Discover" phase in the Considerly platform.

#### *Second step: problem definition and understanding the user's needs:*

The students will analyze the platform's generated results based on tag order or interaction to understand and identify the user's needs. They will put themselves in the user's shoes to empathize with their frustrations and constraints. To define the user, the students will create a character that represents a target audience for their projects.

#### *Third step: formalization of the idea:*

"Creativity is a fact of life, an indispensable quality for engineers, " says Michel Ferlut, director of economic development at École des Mines d'Alès. "When it is a question of creating value in a company, it is through innovation, starting with ideas".

Engineers must be able to think differently and provide innovative solutions to problems. The ability to generate ideas is essential to creating value in a company. Our engineering students

are challenged to generate ideas in teams by identifying user needs and product goals. The ideation phase involves brainstorming in three steps: generating ideas, exploring and developing each idea, and evaluating and shortlisting opportunities.

*Fourth step: prototype and iteration:*

During the prototype and iteration phase, students use Balsamiq software to create low-fidelity prototypes (Figure 5). The prototypes are based on a user "flow" to achieve their goal and are regularly tested throughout the process. The prototypes are evaluated through concept testing on the AI tldv platform, where teams interview target users and observe their behavior and interaction with the interfaces. The AI reporter captures important moments and transcribes the interview. Teams use the data on the Considerly platform for analysis and remote collaboration.

The iterative approach involves creating a prototype, testing it, identifying problems, and proposing solutions (CDIO, standard 5). This method allows for rapid testing and adjustments to achieve actual results: A first concept test aims to evaluate the concept's engagement value and the user flow in the low-fidelity prototype. A second test is carried out on a medium version to confirm the hypotheses of the proposed solutions and the ergonomics of the interface. The final test, usability test, is conducted on a high-fidelity prototype to validate tasks and understanding of the screen level. All tests are iterated based on Checklist iteration (Figure 6).

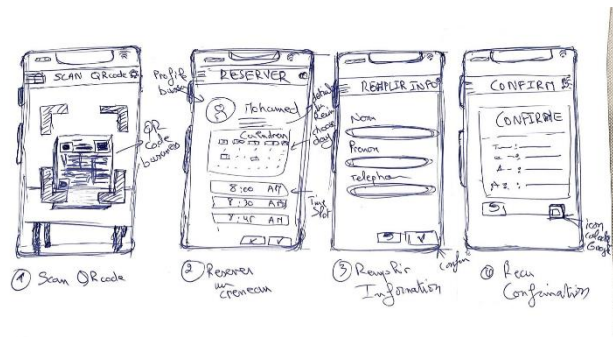


Figure 5. Example of Prototype Low fidelity

**Liste de vérification des itérations**

**Test Concept**

**Itération 1**

1. Faites une liste des 3 à 5 principaux problèmes que votre utilisateur a rencontré lors du test concept : n'oubliez pas à prendre en considération seulement les problèmes rencontrés répétitifs au moins dans deux interviews.
2. Identifiez le type de problème que vous abordez (par exemple, problème d'expérience (usabilité), Problème de concept, nouvelle opportunité).
3. Ecrivez une idée sur la manière de résoudre chaque problème.

**Problème #1** ◊ problème conceptuelle ◊ problème d'usabilité ◊ nouvelle opportunité  
Rédigez le problème

---

**SOLUTION**  
Quelles solutions vous proposer à vos utilisateurs

---

**Problème #2** ◊ problème conceptuelle ◊ problème d'usabilité ◊ nouvelle opportunité  
Rédigez le problème

---

**SOLUTION**  
Quelles solutions vous proposer à vos utilisateurs

---

**Problème #3** ◊ problème conceptuelle ◊ problème d'usabilité ◊ nouvelle opportunité  
Rédigez le problème

Figure 6. Template Checklist -Iteration

### *Fifth step: advanced prototype and deployment*

After developing a sufficiently advanced prototype using Figma and High Fidelity, students create a deployment plan that aligns with their objectives. They share their project's progress and insights from each stage with a detailed report. With their prototype transformed into a demo, they can explain their project's value proposition and make it desirable to their users. This allows them to reach their target audience with a relevant product or service.

### ***Adaptation of the same process in different fields***

To showcase the versatility of the same approach across various domains, we adapted the UX Design process to co-design the evaluation grid for public speaking with the students in an English course at Esprit Business School. This innovative approach aims to enhance student engagement and motivation in language acquisition. The same process was adopted throughout the course, using the NEXTAPP platform Figure 3. In addition, the use of technology facilitated collaboration based on transparent communication, enabling students to interact in real time. But also to practice AI tools to learn about technological environments. A crucial aspect of our project is the integration of interview-based data collection. Firstly, we ensured that the students knew how to formulate questions and had the necessary knowledge to conduct them in order to obtain precise information on the evaluation criteria preferred by the interviewees. This personalized approach ensures that the final grid is tailored to unique learning needs and promotes a more individualized and supportive learning environment.

## **THE IMPACT OF IMPLEMENTING AI-DRIVEN TOOLS IN THE UX DESIGN PROGRAM LEARNING OUTCOMES AND EVALUATION GRIDS**

The table 1 presents comparison between the Program Learning Outcomes (PLOs) of the User Experience (UX) module from 2019 to 2022. It revealed a significant evolution of the learning outcomes showcasing a notable shift in the complexity of skills aligned with Bloom's taxonomy. It also highlights the impact of artificial intelligence (AI) at various stages of the process allowing our students to reinforce skills and attitudes helping them to cope with a changing work environment and society.

### ***Raising the level of depth***

Overall, an increase in the depth of skills was observed. This increase is noticeable in the shift from simple memorisation to a more in-depth understanding of the fundamentals of the UX process (AA1), indicating an evolution towards higher levels of competence and understanding.

### ***Transition to more advanced skills***

The inclusion of 'Testing the prototype with users' (AA5) and 'Iterating and measuring success' (AA7) in the updated 2022 learning outcomes indicates a shift towards higher-level proficiencies. These proficiencies require thorough evaluation and the capacity to iterate and innovate, underscoring the increasing importance placed on advanced skills. (standard 5)

### **Shift in focus to practical application**

The focus of skills is shifting from theoretical understanding to practical application. This is reflected in learning outcomes such as "Analyse user requirements data" (AA3), which has moved from analysis to application. AI is playing a central role in this transformation by automating tasks and freeing up time for learners to focus on advanced skills. The addition of new skills, such as prototype testing with users (AA5) and iteration with success measurement (AA7), suggests a broadening towards more advanced and innovative skills. (Standard 8)

### **Broadening of skills**

Some elements of the 2022 learning outcomes suggest a broadening of the skills expected of learners. For example, "Classify and analyse user requirements data" (AA4) introduces an additional dimension (classify), indicating a diversification of expected skills. (standard 2)

The emphasis is put on the level of understanding of the process rather than presenting the process through one-to-one interviews which explains the absence of 'Produce a presentation of the UX process of your E-commerce project' (AA8) in 2022. This shift highlights how AI is helping to streamline certain tasks, allowing learners to focus their energy on more creative and strategic aspects of UX design. (Standard 8)

In sum, the data suggests that there has been a shift towards more advanced and diverse skills in UX Design learning outcomes from 2019 to 2022. This evolution of learning outcomes, guided by the integration of AI and compliance with CDIO standard 2, prepares IT engineering students to embrace the challenges of a constantly changing industry.

Table 1 : Learning outcomes comparaison

| <b>Learning outcomes</b>                                                          | <b>2019</b>                          | <b>2022</b>                | <b>Note</b>                             |
|-----------------------------------------------------------------------------------|--------------------------------------|----------------------------|-----------------------------------------|
| <b>AA1: Define the basics of the UX process</b>                                   | Level 1 (Knowledge/<br>Memorisation) | Level 2<br>(Comprehension) | Increased<br>level of depth             |
| <b>AA2: Identify a problem and a functionality</b>                                | Level 2<br>(Comprehension)           | Level 3 (Application)      | Change of<br>emphasis to<br>application |
| <b>AA3: Analyse user requirements data</b>                                        | Level 4 (Analysis)                   | Level 3 (Application)      | Decreasing<br>level of depth            |
| <b>AA4: Classify and analyse user requirements data</b>                           | Level 4 (Analysis)                   | Level 4 (Analysis)         | Consistent<br>level of depth            |
| <b>AA5: Test the prototype with users (AA4 in 2022)</b>                           | Not présent                          | Level 5 (Assessment)       | Not<br>mentioned in<br>2019             |
| <b>AA6: Develop prototypes</b>                                                    | Level 5<br>(Assessment)              | Level 4 (Analysis)         | Decreasing<br>level of depth            |
| <b>AA7: Iterate and measure success</b>                                           | Level 5<br>(Assessment)              | Level 6 (Creation)         | Increased<br>level of depth             |
| <b>AA8 : Produce a presentation of the UX process for your E-commerce project</b> | Level 6 (Creation)                   | Not present                | Not<br>mentioned in<br>2022             |

\*(1: Memorise, 2: Understand, 3: Apply, 4: Analyse, 5: Evaluate, 6: Create).

### *How evaluation grid was transformed*

| <b>The evaluation parts</b> | <b>Changes made</b>                          |
|-----------------------------|----------------------------------------------|
| 1. Evaluation Criteria      | Specific criteria added .                    |
| 2. Sub-Criteria             | The grid becomes more specific and detailed. |
| 3. Rating Scale             | The rating scale was changed                 |

Our evaluation approach has undergone a significant refinement through the restructuring of the rating scale distribution between criteria. This reallocation of points places an emphasis on the analytical component during the iteration phase of the evaluation process. Additionally, we have made an augmentation to the rating scale by incorporating points dedicated to the effective utilization of AI tools. This nuanced addition aims to acknowledge and reward the implementation of an efficient approach to leveraging AI technology. Our focus lies in creating meaningful tags, showcasing a commitment to utilizing advanced tools in a way that not only supports project goals but also optimizes the overall UX Design process. In line with the CDIO Standard 11 rubric, we understand the importance of recognizing the need for improvement and benchmarking our current practices. By doing so, we remain committed to maintaining high standards and continuously improving our learning assessment methods.

Crucially, we make sure to pinpoint any deficiencies or inaptitude in our evaluation techniques and make the necessary efforts to rectify these deficiencies.

## **OUTCOMES OF THE SURVEY: CHALLENGES AND LEARNING POINTS**

A survey was conducted with a total of 300 Students from different options of TIC. It was run at the end of the first semester of AY 23 /24, with a focus on the learning experience of students using AI, and its impact on their future career. About 21,66% of the students answered positively to the survey.

The questionnaire designed for the survey aimed to:

1. Analyze the respondents' preferences between integrating the module in the 4th or 5th year of their curriculum.
2. Evaluate the overall interest in the module concerning career development.
3. Summarize the feedback on how to improve the user experience with the module.
4. Investigate the correlation between the perceived helpfulness of AI-user research tools and the desire to use these tools in future projects.
5. Explore any additional comments provided by respondents for qualitative insights.

Some keys findings of the evaluation are as follows: 79% of the respondents believe the module integrates better in the 4th year of engineering programme. In fact, the course in the 5th year is taught 80% online. Throughout their justifications, we noticed that their primary focus lies in enhancing face to face workshops and hands-on sessions, aiming to achieve mastery in all parts of the process. Additionally, there is a strong emphasis on individual tasks, accompanied by straightforward, simple, and constructive instructions. The average interest in the module is approximately 6.56. About 85.48% of respondents are interested in the workshop. This indicates a generally positive reception of the module and a high level of interest in further workshops. The histogram shows the frequency of each score, with the mean

interest score indicated by a dashed red line. This visualization (Figure 7) provides a clearer understanding of how respondents perceive the module's relevance to their careers. Here is a visualization of the distribution of interest scores for career development;

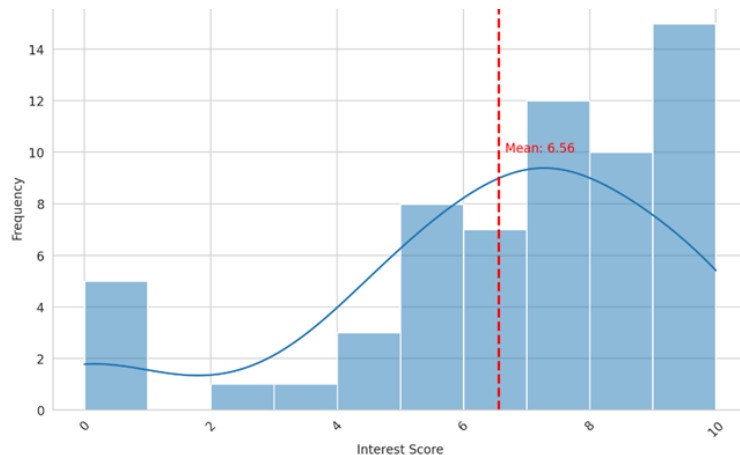


Figure 7. Distribution of interest score for career development

A chi-square test was calculated to examine the correlation between how respondents perceived the module's relevance to their career development and their anticipated use of AI tools in future projects. The results of the test yielded a highly significant p-value of 0.00099, with a calculated chi-square statistic of 27.90 and 9 degrees of freedom. This compelling evidence led to the rejection of the null hypothesis, indicating a significant correlation between the respondents' interest in the career development module and their intention to utilize AI tools in forthcoming projects in fact 90,21% said that they will use AI in their future works. These findings underscore the interconnectedness of perceived educational value and practical application, suggesting that individuals who find a module interesting for their career development are more likely to express a commitment to incorporating the acquired skills into their professional endeavors in the context of the rise artificial intelligence.

## CONCLUSION

In this article, we explored how UX design fits into the CDIO model, particularly in the field of educational engineering. By aligning UX design with the CDIO framework, students gain the skills needed to solve complex, human-centered problems. This promotes creativity, agility and analytical thinking. The UX Design encourages students to consider different perspectives and continually refine their solutions. We conducted a case study at the Esprit School of Engineering to demonstrate how AI-driven tools can enhance the UX Design course. These tools, such as Nextapp.co and Considerly and Tldv have facilitated the user research, prototyping, and iteration processes. They allow students to learn essential aspects of UX Design through real-world scenarios to become the future employee and employer 4.0.

Additionally, we highlighted how AI integration and adherence to CDIO standards influenced the evolution of program learning outcomes and assessment rubrics over time. This shift toward more advanced and diverse skills prepares students to adapt to the ever-changing industrial landscape, fostering innovation and excellence.



The results of the student survey (Figure 8) confirmed the positive reception of the module and the link between perceived educational value and practical application.

Respondents expressed a desire to integrate the module earlier in their course, emphasizing the importance of practical workshops and individual work. In the future, the curriculum will focus on integrating AI to automate tasks and improve the analytical aspect of the module. A project has been launched to create an AI platform that includes the different tools presented in this document. The goal is to create a collaborative space for teachers and students.

In summary, UX Design continues to play a crucial role in engineering education, equipping students with vital skills to thrive in a rapidly changing technology landscape. By adopting AI-driven tools and promoting collaboration, educational institutions can effectively prepare students for the challenges and opportunities of the future.

*Verbatim :*

*Improvements :*



Figure 8. Qualitative insights results survey

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# CHEMICAL ENGINEERING CURRICULUM REDESIGN FOR INTEGRATING UN SDGS USING CDIO

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## **ABSTRACT**

This paper shares the process and outcomes of the efforts from the Diploma in Chemical Engineering (DCHE) offered by Singapore Polytechnic (SP) in integrating the Common Core Curriculum (CCC) using the CDIO Framework. The CCC is an institutional-wide requirement applicable for all SP programs; and uses the United Nations Sustainable Development Goals (UN SDGs) as context of learning generic, broad-based skills and attitudes needed in today's world. This was introduced into the 3-year DCHE program in Academic Year 2022/2023. The authors used the 12 core CDIO Standards to carry out standard-by-standard evaluation of the extent of sustainable development coverage in the existing DCHE curriculum. The paper presents the opportunities where CCC modules could be integrated into the DCHE curriculum to build upon existing skills and attitudes with focus on key areas of chemical engineering and sustainable development as recommended by the Institution of Chemical Engineers, UK (IChemE) that accredits the DCHE program. The paper then explains how the context for learning is set and how selected CCC modules and DCHE modules were paired, forming an integrated curriculum that further strengthens the existing spiral curriculum. New learning activities were created and existing activities were re-designed to integrate the generic skills taught in CCC modules into DCHE modules in the context and applications in chemical engineering. The paper then shares the findings from students on their experience in the new DCHE-CCC way of learning. A quantitative survey was administered for students to rate their learning experiences with an open-ended question for them to express the challenges they faced when they had to apply the skills. Focus group discussions with students were facilitated so that the authors could understand these challenges better. The findings were generally positive with practical comments that form the areas of improvement to address the challenges. Finally, the paper shares future plans for the DCHE course to review the coverage of sustainability in other modules through an integrated curriculum approach.

## **KEYWORDS**

Chemical Engineering, Sustainable Development, Integrated Curriculum, CDIO Standards: 1, 2, 3 and 7, CDIO Optional Standard: 1

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## INTRODUCTION

The Diploma in Chemical Engineering (DCHE) adopted the CDIO Framework as the basis for redesigning its curriculum since 2007. Over the years many changes had been made to align the curriculum with key stakeholder requirements, namely the Singapore Government, Singapore Polytechnic (SP) and the Institution of Chemical Engineers, UK (IChemE) that accredits the program. Its latest course structure is one for spiral curriculum, with effect from Academic Year (AY) 2018/2019, is a direct response to the introduction of the Singapore SkillsFuture Initiative (Cheah & Yang, 2018).

Among the many changes that were made to the DCHE curriculum includes the teaching of sustainable development. In fact, the first effort at integrating education for sustainable development (ESD) started in AY2011/2012, when SP introduced design thinking into the institution. The CDIO Framework had been used as the basis for integrating ESD into the DCHE curriculum (Cheah, 2014; Yang & Cheah, 2014; Cheah, Yang & Sale, 2012; Ng & Cheah, 2010).

The current DCHE course structure features a “dual pathway” of applications of chemical engineering principles: one is the “traditional” chemical process operations in chemical processing industries, and the other is the more recent application in chemical product design. This is the DCHE strategy of achieving what is known as “dual-impact learning” in the CDIO Approach: that students simultaneously learn the domain knowledge at the same time also develop the necessary skills and attitudes in applying the knowledge (Crawley, et al, 2007). Sustainable development are thus integrated into both pathway, with greater emphasis in chemical product design pathway, as this is designed to support Year 3 Final Year Project (FYP), also known as the Capstone Project.

### ***DCHE, Common Core Curriculum and ESD***

In AY2020/2021, SP Management announced that all diplomas will have to include Common Core Curriculum (CCC), and 2 diplomas namely Diploma in Optometry and Diploma in Aeronautical Engineering will do the pilot in the same year. The CCC is designed to prepare SP students for a disruptive world that is ever-changing. Technological disruptions have created new and increasingly sophisticated job roles, hybrid job roles which require graduates to have diverse skill sets. These in-demand skills include both emerging digital skills and human skills in artificial intelligence (AI), collaboration and persuasion, and critical thinking. The CCC provides an integral and inter-disciplinary learning experience to address the wicked problems of the world framed by the United Nations’ Sustainable Development Goals (UN SDGs), which run thematically across the 10 CCC modules. The details are published by Cheah, Lim and Chao (2022).

The first module in CCC introduced into Year 1 Semester 1 is *Thinking Critically about the UN SDGs*, and it sets the context for learning. Only selected modules from CCC are required for pairing with the diploma’s domain core modules. Each diploma is at the liberty to decide how best to pair its domain core modules with the CCC modules, to suit the diploma’s own learning context. Other CCC modules, e.g. *Artificial Intelligence and Its Impact* can be delivered as standalone module. DCHE introduced its revised curriculum integrating CCC in AY2022/2023 is shown in Figure 1.

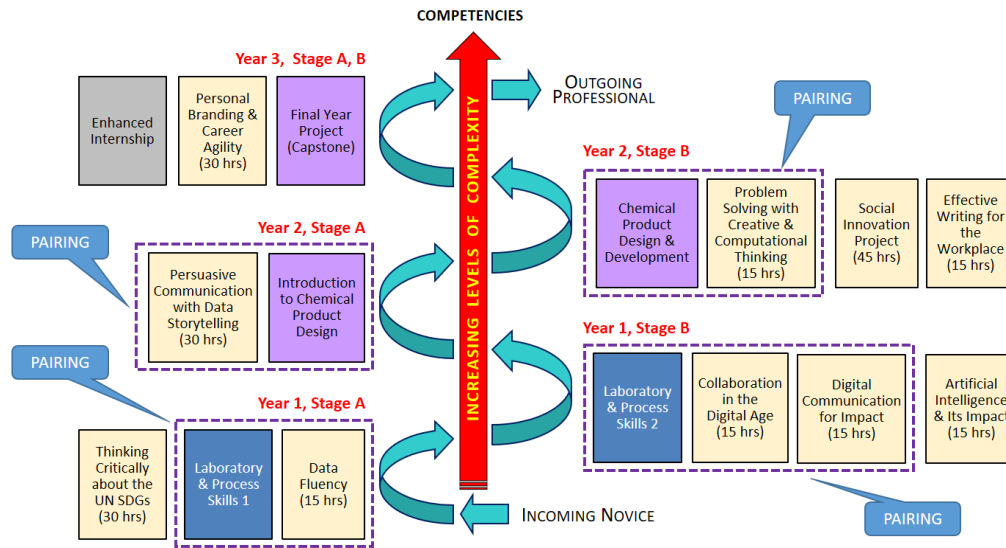


Figure 1. Paired Core Modules in the DCHE Spiral Curriculum Course Structure

## USING CDIO CORE STANDARDS TO GUIDE DESIGN OF ESD IN DCHE

The 12 core CDIO Standards were used to carry out a standard-by-standard evaluation of to what extent, elements of sustainable development had already been covered in existing DCHE curriculum; and what else needs to be done. The result is shown in Table 1. Note that in this table, the term “CCC skills” is used to denote skills and attitudes to be developed via the CCC modules.

Table 1. General Guiding Principles for Curriculum Design for ESD using CDIO and CCC

| Core Standard No.        | Curriculum Design to include Sustainable Development                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|--------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. The Context           | Align the context for learning sustainable development within a given disciplinary setting is with the focus area(s) of key stakeholders that the diploma is serving. All diplomas can take reference from the Singapore Green Plan 2030, which spelt out many initiatives and targets grouped under 5 themes of City in Nature, Energy Reset, Sustainable Living, Green Economy, and Resilient Future. Professionally accredited diploma can also benefit from guidance from the accreditation body, in specific areas of interest to the discipline.                                                                                            |
| 2. Learning Outcomes     | Connect domain-specific learning outcomes with requirements from CCC’s more generic learning outcomes. These CCC learning outcomes can serve as “building blocks” to develop higher-order skills and attitudes that are needed in ESD. Together with the CDIO Syllabus, identify other skills and attitudes that are needed to complement the generic CCC skills for delivering the domain area learning outcomes; in selected domain core modules and suitably contextualized to provide the desired proficiency levels.                                                                                                                         |
| 3. Integrated Curriculum | Ensure the progressive development of skills and attitudes needed for sustainable development via appropriate pairing with CCC. This means the outcomes of a given pairing should serve to enhance and extend learning beyond the paired modules. The notion of “deliberate practice” (Ericsson, 2008) would suggest that students be exposed to issues of sustainable development in other core modules. This will lead to the systematic development of skills from both horizontal integration (i.e. serving as reinforcement) and vertical integration (i.e. serving to level up) students’ competencies in addressing sustainability issues. |

Table 1. (continued)

| Core Standard No.                              | Curriculum Design to include Sustainable Development                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4. Introduction to Engineering                 | Introduce the context of learning about specific UN SDGs relevant to the discipline, through Year 1 Semester 1 module such as <i>Introduction to Chemical Engineering</i> that introduces students to the profession. This module can be also “unofficially paired” with “introductory” standalone CCC module <i>Thinking Critically about the UN SDGs</i> .                                                                                                                                                                                                                                          |
| 5. Design-Implement Experiences                | Review existing curriculum on the use of project-based learning in core modules – either as standalone modules in various years of study; or via a group of modules in a deliberately designed “project spine” across stages of study from Year 1 to Year 3. During the review process, one can identify opportunities to include selected UN SDGs as the context for project work. The CCC module <i>Sustainable Innovation Project</i> itself is a multi-disciplinary project will remain as standalone; to enable students from different courses to work together in a multi-disciplinary manner. |
| 6. Engineering Learning Workspaces             | Make existing learning workspaces more “conductive” to support discussing about sustainability issues, through simple efforts such as highlighting the facilities’ on-going efforts on energy-saving, water conservation, use of less chemicals, waste recycling, etc. Good management practices, such as ISO 14001 should be integrated as part of as laboratory / workshop briefing; or day-to-day operations where applicable, for example housekeeping after the conclusion of each experiment.                                                                                                   |
| 7. Integrated Learning Experiences             | Review existing learning activities (lab experiments, assignments, etc) for opportunities to include added emphasis on sustainable development within the disciplinary domain. These integrated learning experiences should take into considerations the skills and attitudes already introduced in CCC. They should preferably address several UN SDGs using the same learning context for an activity, to reflect the interconnectedness of these 17 goals; and to engage students in using a range of key competencies needed for sustainable development.                                         |
| 8. Active Learning                             | Explore ways to use active learning in classroom settings. These should focus on peer learning in a collaborative manner with the help of technologies (such as Jamboard or Google Docs) to elicit different viewpoints from students in the context of appropriate UN SDGs to develop key competencies needed for sustainable development.                                                                                                                                                                                                                                                           |
| 9. Enhancement of Faculty Competence           | Provide professional development programs that focus on developing lecturers’ competency to teach and facilitate development of various CDIO skills in the context of sustainable development, such as emphatic thinking, systems thinking, transdisciplinary thinking, etc                                                                                                                                                                                                                                                                                                                           |
| 10. Enhancement of Faculty Teaching Competence | Provide professional development programs that focus to develop competencies in providing integrated learning experiences, using active and experiential learning methods, and assessing student development of skills and attitudes in the context of sustainable development, as described in Standards 7, 8 and 11.                                                                                                                                                                                                                                                                                |
| 11. Learning Assessment                        | Use “Constructive Alignment” to ensure “shared” assessments between the paired CCC modules and domain core modules are designed such that the assessments in domain core are always aligned to the learning outcomes from CCC modules (see also Standard 2) in any learning tasks that engage students in developing sustainable development competencies.                                                                                                                                                                                                                                            |
| 12. Program Evaluation                         | Carry out review of integration of sustainable development in the curriculum via the usual self-evaluation process using the CDIO Core Standards; to supplement the usual module review and course review; with a view of continual improvement to enhance sustainability issues. Identify best practices seen in modules consistent with each standard’s rubrics.                                                                                                                                                                                                                                    |

The remaining paragraphs in this section provide examples that elaborates on how Standards 1, 2 and 3 are applied to guide the integration of sustainable development into Year 1 of the DCHE curriculum via pairing with CCC using the design guidelines based on the CDIO Framework presented in Table 1.

The approach to designing an Integrated Learning Experience (CDIO Core Standard 7) for a core module is shared in the next section. The section after that provides examples of the learning activities in DCHE Year 1 curriculum that involves the pairing with CCC.

### ***CDIO Core Standard 1: Setting the Context for Sustainable Development***

DCHE had introduced chemical product design into its curriculum, focusing on sustainable development when it adopted CDIO to redesign its curriculum (Cheah, 2014; Yang & Cheah 2014). DCHE had already aligned its focus for FYP, based on the IChemE focus areas on challenges in Energy, Food & Nutrition, and Water as highlighted in its Chemical Engineering Matters, now in its 3rd Edition. (IChemE, 2016). It was therefore quite straightforward for DCHE to identify which UN SDGs to focus its coverage on. The work that needs to be done is to explicitly link the IChemE focus areas to the relevant UN SDGs to make clear to students how learnings from the CCC can be linked to what they will learn in DCHE. This can be further contextualised to focus on the Singapore's own effort as outlined in the Singapore Green Plan 2030 in general, and chemical industry in particular, based on the sustainable development initiatives at Jurong Island (EDB, 2021).

### ***CDIO Core Standard 2 and CDIO Syllabus: Complementary with CCC Learning Outcomes***

The desired outcomes from ESD had been extensively reviewed (Cheah, 2021). The knowledge, skills and attitudes needed to support sustainable development had been identified by various authors such as Lazano, et al, 2017; Scarff-Seatter & Ceulemans, 2017; Barth, et al, 2007). In the current thinking on ESD, the outcomes to be achieved is that of third-order, transformative learning (Mezirow, 2003; Sterling, 2011). These learning outcomes can be written using the CDIO Syllabus, which is aligned to the UNSECO Framework (Rosen, et al, 2019).

An important point to note here is the “competency in sustainable development” is a high-order competency that is taken as the aggregation and build-up from a number of foundational skills and attitudes. The human skills and digital skills covered in the CCC modules provide some of these foundational skills and attitudes, complementing other skills and attitudes covered in the DCHE syllabus such as growth mindset, hypothesis testing, critical thinking, etc. Systems thinking in particular – as covered in CDIO Syllabus version 3.0 Part 2.3 – is very important in sustainable development as it emphasized thorough consideration of decisions made today that are seemingly beneficial but may adversely impact the environment or society into the future; in what is termed “unintended consequences”.

### ***CDIO Core Standard 3: Identifying pairing with CCC***

In the CDIO integrated curriculum, and in particular for the DCHE spiral curriculum, requires thoughtful “pairing” with selected CCC modules, via both horizontal integration (reinforcement across several modules in the same stage) and vertical integration (levelling up across modules from stage to stage) integration to progressively develop knowledge, skills and attitudes required. Since the CCC is conceptualised to offer each diploma the flexibility of deciding on its own pairing, DCHE selected domain core modules to pair with which CCC modules based on the objective of always to strive for “dual-impact learning” – a hallmark of CDIO-type curriculum.

In the context of ESD in DCHE, the learning of sustainability principles can be used in both chemical plant operation and chemical product design using the same set of chemical engineering principles (Cheah, 2021). The pairing selection is therefore based on how the CCC modules can strengthen existing coverage of skills and attitudes in the DCHE curriculum



similar to how the Critical Core Skills of the Singapore Skills Framework are to be used: i.e. “Skills to Build Skills”.

For example, in Year 1 Semester 1, *Data Fluency* is paired with *Laboratory and Process Skills 1 (LPS1)*, because the DCHE domain core deals with challenges in conducting laboratory experiments and working in pilot plants, and both require skills in data handling. Furthermore, big data had earlier been pin-pointed as a focus area for DCHE when we reviewed our curriculum in response to the needs of Skills Framework for the Energy and Chemicals Sector with consideration to the impact of Industry 4.0 on the chemical processing industry (Cheah & Yang, 2018). Having the right kind of data (in terms of reliability and validity) is important before such data can be used.

## THE CDIO WAY TO INTEGRATE ESD INTO CURRICULUM WITH CCC

The steps below describe a simplified approach to integrate sustainable development into a curriculum, i.e. at the diploma-level. The objective is to set high-level learning outcomes at the course level – often captured in the Course Aims and the sub-aims:

1. Ascertain the context for learning by referring to requirements of key stakeholders for your diploma with respect to sustainable development and identify several appropriate UN SDGs.
2. Write some high-level outcomes for the desired transformative learning, based on the selected UN SDGs and focus areas of sustainable development of your course.
3. Identify the competencies (knowledge, skills and attitudes) needed to support sustainable development in the context and outcomes identified above.

The required competencies will have to be gradually developed via an integrated curriculum (CDIO Core Standard 3). This paper will not report on the approaches to integrating sustainable development via projects (i.e. CDIO Core Standard 5 Design-Implement Experiences), as this had been addressed elsewhere by Yang & Cheah (2014) on DCHE’s “project spine”. The steps described below follows from the steps above in translating the context and outcomes desired at the course-level down into learning tasks (known as integrated learning experiences, as per CDIO Core Standard 7) in a module that was paired with one or more CCC modules. The DCHE Course Management Team made the decision on how best to pair the CCC modules with the diploma’s own domain core modules. These domain core modules are the ones that are most amenable to include issues related to sustainable development. In other words, they provide the natural context for inclusion of the selected UN SDGs while remembering that one domain core module can be paired with more than one CCC modules.

1. Identify at least one UN SDG that fits the topics covered in the domain core module.
2. Identity a plausible real-world scenario involving sustainability issues targeted by the selected UN SDG(s), and write a brief description of the scenario.
3. Identify the competency (knowledge, skills and attitudes) needed for the scenario and write the learning outcomes using suitable taxonomy (e.g. Bloom) into the module syllabus.
4. Identify any prior knowledge acquired earlier, as well as skills and attitudes developed earlier that are needed to support the desired competency.

5. Develop the assessment scheme (CDIO Core Standard 11) that include the required evidence of learning; and check for constructive alignment.
6. Prepare scaffolding that support the development of the desired competency, e.g. performance rubrics.

Note that the approach suggested above is equally applicable to modules that are not being paired with CCC. In fact, it can be envisioned that to effectively develop the necessary sustainability competency as one of the desired graduate attributes, significant numbers of such integrated learning experiences need to be included into a 3-year diploma program.

The remainder of this paper is devoted to such a discussion, focusing on work done in Year 1 DCHE. As mentioned in earlier section, the revised DCHE curriculum featuring CCC was introduced in AY2022/2023; with the pairing as shown in Figure 1.

## WORK DONE IN FIRST YEAR DCHE PAIRED MODULES

Key features in the pairing of DCHE core modules with CCC module are shown in Table 2 for *Data Fluency* paired with *LPS1* for Semester 1, Year 1; and Table 3 for *Digital Communication for Impact and Collaboration in the Digital Age* paired with *Laboratory & Process Skills 2 (LPS2)* for Semester 2, Year 1.

Table 2. Pairing for DCHE Year 1 Semester 1 Curriculum

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>CCC: <i>Data Fluency</i> – Module Learning Outcomes</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <ul style="list-style-type: none"> <li>• Show examples on the prevalent use of (big/large) data in tackling UN SGDs</li> <li>• Formulate specific data questions that exhibit aggregated perspectives by using words like typically, generally, on average, etc</li> <li>• Illustrate the different data collection methods (archives, surveys, experiment, etc)</li> <li>• Join and clean data sets from multiple sources</li> <li>• Classify data into qualitative and quantitative</li> <li>• Explore data using different visualizations (Card, Bar, Pie, Word cloud)</li> <li>• Explain the aggregated view of data using various numerical summaries (e.g., Sum, Average, Min, Max, CountD, Count, Standard Deviation, Median)</li> </ul> |
| <b>DCHE: <i>Laboratory &amp; Process Skills 1</i> – Assignment Learning Outcomes</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <ul style="list-style-type: none"> <li>• Investigate the type of flowmeter used in household for measuring water consumption</li> <li>• Explain the working principles of 2 different types of water flowmeter used in the chemical industry</li> <li>• Explain the importance of understanding the working principles of various flowmeters</li> <li>• Compare and contrast between flowmeters used in household vs. industry</li> <li>• Explain feasibility of replacing household flowmeter with industrial flowmeter</li> </ul>                                                                                                                                                                                                             |
| Assignment in Brief:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <ul style="list-style-type: none"> <li>• UN SDG 6: Clean Water and Sanitation</li> <li>• Students used the water consumption in Singapore households data and prepared a dashboard using PowerBI to identify possible trends with possible factors such as housing types and number of household members; and draw insights</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                          |
| Assessment:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <ul style="list-style-type: none"> <li>• Students were assessed based on how well they understood the working principles of flowmeters, how the appropriate flowmeters were selected and used to measure water consumption in Singapore households versus those used in the industry.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                |

Table 3. Pairing for DCHE Year 1 Semester 2 Curriculum

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>CCC: <i>Digital Communication for Impact</i> – Module Learning Outcomes</b></p> <ul style="list-style-type: none"> <li>• Identify the key differences between digital and face-to-face communication</li> <li>• Compare and contrast digital communication platforms / tools and build an understanding of their benefits and limitations</li> <li>• Examine the different building blocks of impactful digital communication</li> <li>• Design and apply key principles when crafting impactful digital communication (written, visual, audio and video) to engage and inspire your target audience</li> <li>• Discuss what it means to be a responsible Digital Citizen</li> <li>• Demonstrate an understanding of and respect for the rights and obligations of using and sharing intellectual property</li> <li>• Describe strategies to cultivate and manage digital identity, personal data and privacy</li> <li>• Demonstrate positive, safe, legal and ethical behaviour when using digital communication</li> </ul> |
| <p><b>CCC: <i>Collaboration in the Digital Age</i> – Module Learning Outcomes</b></p> <ul style="list-style-type: none"> <li>• Identify personal strengths and weaknesses</li> <li>• Identify own roles and responsibilities and their contributions towards the achievement of team goals</li> <li>• Set SMART individual and team goals to achieve project outcome</li> <li>• Apply effective communication techniques to encourage participation and collaboration in a team (F2F/digital)</li> <li>• Demonstrate positive digital body language and EQ throughout the online interaction</li> <li>• Accept and provide feedback in a considerate and constructive manner</li> <li>• Use simple project planning and collaboration tools to manage team projects</li> </ul>                                                                                                                                                                                                                                                     |
| <p><b>DCHE: <i>Laboratory &amp; Process Skills 2</i> – Assignment Learning Outcomes</b></p> <ul style="list-style-type: none"> <li>• Classify activities for a project in a given context to the stages of Conceive-Design-Implement-Operate</li> <li>• Understand the functions of key departments in a typical company in the Energy &amp; Chemicals Sector, and the job roles in and the responsibilities of these departments</li> <li>• Identify the key departments that will be involved in the activities for a project in a given context</li> <li>• Identify key factors of consideration about a project in a given context</li> <li>• Relate the functions and responsibilities in key departments to the factors that need to be considered for a project in a given context</li> <li>• Compare and contrast the use of seawater vs cooling water as cooling medium in a given context.</li> </ul>                                                                                                                    |
| <p>Assignment in Brief:</p> <ul style="list-style-type: none"> <li>• UN SDG 14: Life Below Water</li> <li>• Students worked effectively as a team to identify the roles and responsibilities of departments involved in the design, installation and operation of a heat exchanger to cool a hot product stream. Then, they collaborated on an online platform to study the pros and cons of the use of cooling water or seawater as the cooling medium for the heat exchanger, and draw insights to create a video for a digital communication platform to educate members of the public.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <p>Assessment:</p> <ul style="list-style-type: none"> <li>• Students were assessed on the effectiveness of their teamwork, quality of online discussion, provision of relevant and sufficient information needed to communicate intent to target audience in video created and how well key principles of impactful digital communication were used (CCC), thoroughness and depth of consideration when deciding between use of cooling water or seawater as cooling medium for the heat exchanger.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

## DISCUSSION OF FIRST YEAR STUDENTS' LEARNING EXPERIENCE

In this first run of CCC in DCHE, a survey designed to evaluate the students' learning experience in the paired modules with quantitative questions and an open-ended question was administered to 60 students from the AY2022/2023 cohort in the DCHE course. Participation in the survey was on a voluntary basis and students' names were not collected to retain anonymity during analysis of the survey results. A focus group discussion was subsequently conducted with students randomly selected from the three classes surveyed to triangulate the survey results.

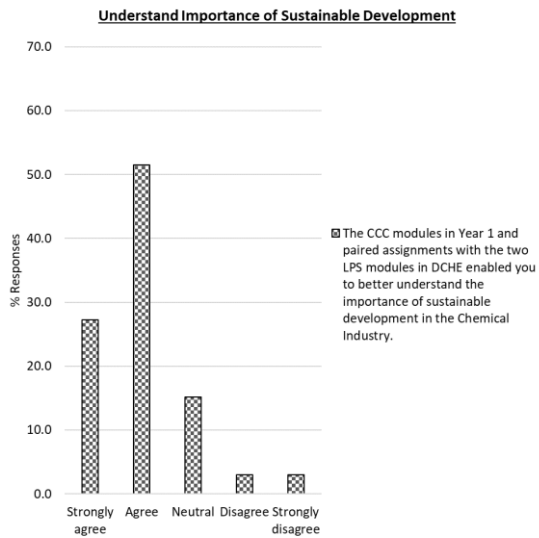


Figure 2. Understand Importance of Sustainable Development

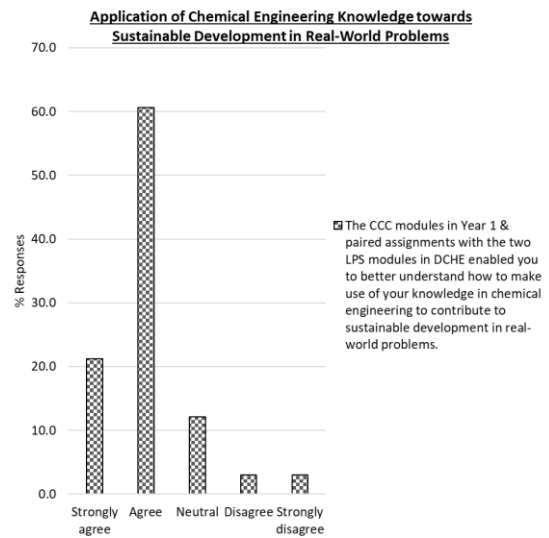


Figure 3. Ability to Apply Chemical Engineering Knowledge towards Sustainable Development in Real-World Problems

From the survey, more than 75% of students agree or strongly agree that the CCC modules in Year 1 and paired assignments with the LPS modules in DCHE enabled them to better understand importance of sustainable development in Chemical Industry (78.8%; Figure 2) and allowed them to better use knowledge in chemical engineering to contribute towards sustainable development in real-world problems (81.1%; Figure 3).

When students were asked specifically whether the assignments crafted for the paired modules enabled them to apply the skills learnt in CCC modules to LPS modules, most agree or strongly agree that they were able to apply skills such as data cleansing and analysis (72.8%), teamwork (78.8%) and communication (78.8%) to assignment scenarios contextualised to their core discipline of study (Figure 4). More than 72% of students agree or strongly agree that they were confident in using these skills in the next year of study (Figure 5).

In the open-ended survey question, students were asked to explain the key challenges faced when they had to apply the skills learnt in CCC modules to the LPS modules in general. A quarter of students mentioned that that they found it hard to link the CCC modules and LPS modules. One student elaborated that “*Sometimes I do not see the link between the two modules and sometimes I may not know when to apply these knowledge learnt in CCC modules to the LPS modules*”.

These results suggests that the pairing of the CCC (*Data Fluency, Collaboration in the Digital Age and Digital Communication for Impact*) with DCHE (*LPS1 and LPS2*) modules and assignment designs were appropriate and enabled students to see the link and apply the skills learnt from a generic module to their core domain modules when given specific assignments.

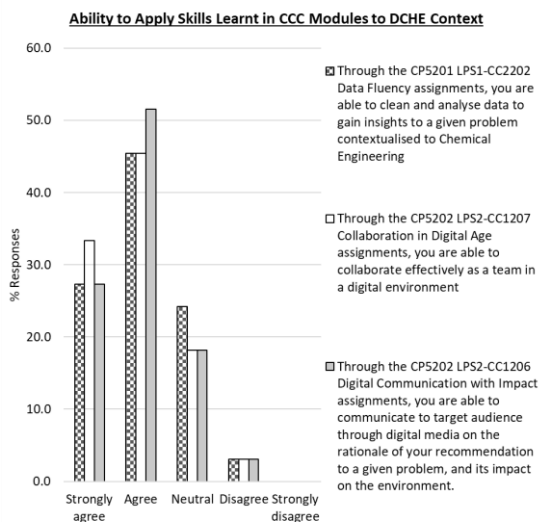


Figure 4. Ability to Apply Skills Learnt in CCC Modules to DCHE Context

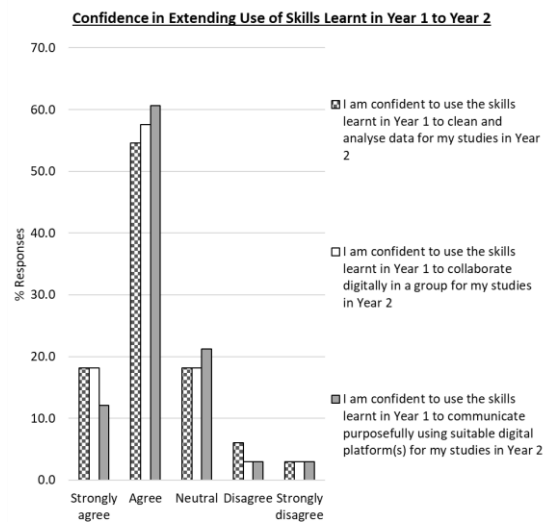


Figure 5. Confidence in Extending Use of Skills Learnt in Year 1 to Year 2

## FUTURE AREAS OF IMPROVEMENT

The work done reported in this paper is based on the first run of CCC in DCHE. It provided the lecturers involved in the teaching of *LPS1* and *LPS2* much valuable experience in understanding the requirements of CCC. In this section, several ideas to improve the pairing between CCC modules and DCHE core modules are outlined.

Firstly, for *LPS1*, the current assignment as shown in Table 2 can be modified with one that aligns better with the DCHE curriculum integration effort, more specifically to deepen students' skills in creating better data visualisation using the skills developed in *Data Fluency*. With that in mind, an activity was introduced where students created various charts explaining the relationship how certain process variables (such as temperature, pressure or composition) will affect mixture properties (such as density, specific heat capacity, viscosity, boiling points, etc). These are big data of interest in both chemical processing and product design. To supplement this learning activity, a scenario could be crafted that centers around process and/or equipment design and/or selection when seawater is used for cooling in a chemical plant. This will tie in well with the assignment in *LPS2* which already focused on using seawater in chemical processing industry as mentioned in Table 3.

Secondly, for *LPS2*, students' skills in data visualisation can be further strengthened by tapping onto an existing laboratory experiment on mixing and leaching. Besides learning about key principles in chemical engineering, students also learnt about design of experiments and importance of collecting good data; namely in terms of data validity and reliability. Students can learn to collaborate in collecting data for 8 experimental designs where each student team will investigate 2 different experimental designs. Each team will then share the finding with other teams where eventually all teams will have all the necessary data to analyse, generate discussion and create impactful presentation using the skills gained from *Digital Communication for Impact*.

Thirdly, from Figure 1, in DCHE Year 1, there are 2 other standalone CCC modules; namely *Thinking Critically about the UN SDGs* in Semester 1 and *Artificial Intelligence and its Impact* in Semester 2. As noted in Table 1, core domain module such as *Introduction to Chemical Engineering* can be “unofficially paired” with *Thinking Critically about the UN SDGs*. This will further enhance the DCHE curriculum integration to explicitly make the connection between modules. Another “unofficially” pairing can be done in Semester 2 is with *Artificial Intelligence and its Impact*, contextualised in terms of application of artificial intelligence in water management to align with the assignment in *LPS2* described earlier.

Lastly, the skills developed in *LPS1* and *LPS2* can be enhanced in the context of chemical process plant operation when the students move on to Year 2 where they will complete 2 more skills-based core modules (not shown in Figure 1). Likewise, how skills learnt in *Data Fluency*, *Digital Communication for Impact*, and *Collaboration in the Digital Age* can be further enhanced in Year 2 modules.

The DCHE Course Management Team will conduct a review to map relevant UN SDGs to domain core modules. This will further enhance the integration of CCC skills in the domain core modules is through the use of relevant examples. This learning shall be made explicit to students so that they purposefully apply the knowledge on UN SDGs to the chemical engineering context. The terminal objective is to enable students to better understand the importance of sustainable development in the chemical industry and allow them to use their knowledge in chemical engineering to contribute to sustainable development in a real-world context.

## **CONCLUSION**

The Course Management Team adopted the approach of using the 12 core CDIO Standards to carry out a standard-by-standard evaluation of the extent of sustainable development coverage in the existing DCHE curriculum. This approach is found to be constructive because it guides the evaluation process in a structured and systematic manner.

The findings from DCHE students of their first year experiences provide positive indication that the Course Management Team’s decision of pairing CCC modules with the diploma’s domain core modules as shown in Figure 1 enable students to see the connection between the skills learnt and students could apply these skills in different context. At the same time, students developed confidence to extend the use of these skills learnt in first year to second year and beyond.

In conclusion, our study has shown that the assignment pairing when executed in a purposeful manner enabled students to understand how and when to use the appropriate skills and apply them at various stages of the course.

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# RESEARCH AND PRACTICE OF THE PROJECT-DRIVEN LINEAR ALGEBRA PRACTICE TEACHING MODEL

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## ABSTRACT

Linear algebra courses are the foundation of engineering disciplines related to artificial intelligence and robotics, and its related knowledge has a wide range of applications in image processing, machine learning, mechanical arm movement, etc. To distinguish from the traditional linear algebra teaching mode, which emphasizes theory and neglects practice and application, and learns from the engineering CDIO education concept, we carry out project-driven linear algebra practical teaching in the linear algebra course. By designing practical projects and assigning practical tasks, students form project teams and complete the project tasks in a specified time through division of labor and cooperation. Teachers design corresponding assessment evaluation standards, and students in the group present and publicize the methods and results of completing the task. Through self-assessment, group evaluation, and teacher evaluation methods, practical achievements are obtained. In the practice of the project-driven linear algebra practical teaching model, students not only deepen their understanding and application of linear algebra concept knowledge, but also enhance their practical hands-on ability, improve their team spirit and communication skills, understand the application prospects of linear algebra courses, and lay the foundation for future study in artificial intelligence and related fields.

## KEY WORDS

Linear algebra courses, Engineering education, Project-driven teaching, CDIO Standards: 1,2,3,7,8,10

## INTRODUCTION

Linear algebra, along with mathematical statistics, furnishes much of the theoretical underpinning for the development of computer science and engineering, such as image processing, signal processing, machine learning, artificial intelligence, etc., and provide tools for solving many practical problems, such as optimization problems, image processing, network optimization, etc. In summary, linear algebra is a very important branch of mathematics. It has a wide range of applications in mathematics, computer science, physics and other fields. It is the foundation of many important theories and practical problems. As an important basic mathematics course, the traditional method of teaching linear algebra courses is still to talk about definitions, theorems, derivation proofs and calculations. Students often feel boring, abstract, and difficult to understand some conceptual theories. Especially they cannot see how linear algebra is applied. Therefore, from the perspective of teaching effectiveness, students are not motivated to learn. The application of linear algebra only stays

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in the first lesson—the introduction class. With the advent of the era of artificial intelligence and big data, technology updates are getting faster and faster. The basic role of linear algebra applications is becoming more apparent. The teaching mode of linear algebra courses urgently needs to be updated.

According to the CDIO initiative, its goal is to provide students with an engineering education that emphasizes engineering fundamentals and is based on the conception design implementation operation (CDIO) background environment of real-world products, systems, and processes. (Malmqvist, J. (2020)) This education aims to cultivate students' solid engineering fundamental theories and professional knowledge, and through close integration with society and enterprises, enable students to learn and practice in real engineering fields, thereby improving their engineering literacy and comprehensive abilities. The linear algebra course can draw on the CDIO educational philosophy of engineering education as a basic course for engineering education, integrate practical aspects into teaching, target real problems, allow students to actively conceive and design solutions to problems, understand linear algebra knowledge in the process of solving problems, bridge the gap between theory and reality, and improve students' engineering literacy and interdisciplinary comprehensive abilities.

There are multiple teaching methods that can be used to achieve the CDIO standards, among which project-based teaching is a teaching method that focuses on projects, takes students as the main subjects, and is guided by teachers (Zarestky, J. (2022)). Based on teaching objectives and students' actual situations, teachers design a series of projects related to practical engineering problems to enable students to master knowledge and skills in the process of solving problems. (Lehmann et al., 2008) Project-driven teaching can stimulate students' interest and motivation in learning, cultivate their teamwork and problem-solving abilities, and also promote interaction and communication between teachers and students. (Bernhard, J. (2020)) It cultivates students' sustainable development abilities in project-based teaching. Due to the wide applicability of linear algebra, it provides materials for practical teaching of linear algebra. It is feasible to explore practical problems and cases that can be applied as practical content for linear algebra courses, and carry out project-based practical teaching of linear algebra.

The following sections introduce the background for offering a linear algebra course, the methodology, results, discussion, and analysis of project-driven practical teaching of linear algebra. Finally, the conclusion is presented.

## **Background**

The linear algebra course involved in this article is offered to second-year undergraduate students in the Zhiyuan Experimental Class and the School of Information Engineering at our university. The total credits of students in four years should not exceed 173 credits, and the professional education credits should not exceed 120 credits. Linear algebra is a fundamental professional course with 48 class hours and 3 credits. The majors that take this course include intelligent computing, intelligent manufacturing, data science and big data technology, computer science and technology, electrical engineering and automation, and internet of things engineering. There are three teaching classes, each taught by a different instructor. The course objectives and evaluation methods are shown in Table 1 and Table 2 respectively.

Table 1. Course Objectives of Linear Algebra and Supporting Graduation Requirements

| Linear Algebra (MATH208) |                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                     |
|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|
| Course Objectives        | Course objective description                                                                                                                                                                                                                                                                                                                                                                                                                     | Support strength for graduation requirements(H M L) |
| Course Objectives 1      | Through the study of this course, students will be able to describe concepts such as the number of rows and columns, matrices, systems of linear equations, vectors, vector groups, similar matrices, quadratic forms, etc. They will also be able to identify and explain relevant theories related to matrices, systems of linear equations, vector theory, similar matrices, and quadratic forms, and express and infer relevant conclusions. | H                                                   |
| • Course Objectives 2    | Through the identification, comparison, and deduction of the learned linear algebra knowledge, summarize, reorganize, and deal with related problems; design problem-solving ideas for some practical or mathematical problems, compile MATLAB commands, and combine relevant theoretical knowledge to draw conclusions.                                                                                                                         | M                                                   |

Table 1 outlines the detailed descriptions, evaluation criteria for the two Course objectives of the linear algebra course. Table 2 outlines evaluation criteria and grade proportion. Among the evaluation criteria, the experimental component accounts for 10% of the grade(The dotted line section). Prior to adopting the project-driven practical model, this experimental content primarily involved using Matlab commands for determinant calculations, matrix operations, solving linear equations, finding eigenvalues and eigenvectors, and addressing some simple application problems. However, these were not authentic real-world problems. In the era of artificial intelligence and big data, these experiments have become outdated, particularly for majors in the School of Information Engineering that are highly correlated with professional graduation requirements.

The research content of this article focuses on improving the previous teaching model related to the experimental component of the evaluation criteria by adopting a project-driven practical teaching model. The following section introduces the main methodologies of the project-based practical teaching model.

Table 2.Evaluation criteria and grade proportion

| Order number | Course objectives | Evaluation criteria and grade proportion(%) |                 |                  |                                |                  | Grade proportion/Percentage of grades(%) |
|--------------|-------------------|---------------------------------------------|-----------------|------------------|--------------------------------|------------------|------------------------------------------|
|              |                   | Classroom test(10%)                         | Home work (10%) | Experiment (10%) | Periodic assessment/test (10%) | Final exam (60%) |                                          |
| 1            | Objectives 1      | 10%                                         | 10%             |                  | 8%                             | 42%              | 70%                                      |
| 2            | Objectives 2      |                                             |                 | 10%              | 2%                             | 18%              | 30%                                      |

|                         |     |                                                                                                                                                                                                                                                                                                                                                                                           |     |     |     |      |
|-------------------------|-----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|-----|------|
| Total                   | 10% | 10%                                                                                                                                                                                                                                                                                                                                                                                       | 10% | 10% | 60% | 100% |
| Final assessment format |     | <input checked="" type="checkbox"/> Closed-book written examination <input type="checkbox"/> Open-book written examination <input type="checkbox"/> Course paper (design) <input type="checkbox"/> Course report<br><input type="checkbox"/> Practical computer operation <input type="checkbox"/> Experimental operation<br><input type="checkbox"/> Additional items (Please indicate). |     |     |     |      |

## Methodology

Project-based practical teaching involves teachers assigning open-ended project tasks, with students working collaboratively in groups of 4-6 individuals, freely formed. The teacher designs five practical projects (see Table 3), with each project containing 4-5 tasks to be completed by the student groups within a set time frame of 15 to 30 days. Students are required to conduct literature reviews, design problem-solving approaches, and utilize computer software to achieve the desired outcomes prescribed by the tasks. Through this process, students acquire new knowledge and methodologies, gaining a better understanding of linear algebra concepts. Each project provides room for student creativity, such as exploring alternative image compression techniques through literature research and implementing them using software, learning additional image edge detection methods, and explaining observed phenomena using their knowledge of linear algebra. Finally, students summarize and present their findings. The completion of these tasks fosters computational thinking skills, executive abilities, and team collaboration among students during the practical process.

To evaluate the quality of students' task completion, a grading method is adopted that combines intra-group self-evaluation (20%), inter-group peer evaluation (30%), and teacher evaluation (50%) to derive a comprehensive score. The grading criteria are outlined in Table 4. The project design and evaluation criteria correspond to the CDIO standards. Projects are selected from real-life problems, providing students with an emphasis on the Conceive-Design-Implement-Operate (CDIO) process using fundamental knowledge of linear algebra, which aligns with CDIO Standard 1.

Table 3 Linear Algebra Practical Project

| Project Name                              | Relevant Linear Algebra Knowledge Points                                                                       | Project Code | Project Implementation                          |
|-------------------------------------------|----------------------------------------------------------------------------------------------------------------|--------------|-------------------------------------------------|
| Color Image Processing                    | Addition, Subtraction, and Scalar Multiplication of Matrices                                                   | A            | First Practice (Choose one from two options)    |
| Geometric Transformation of Plane Figures | Linear Transformation and Matrix Multiplication                                                                | B            |                                                 |
| Color Image Compression                   | Eigenvalues and Eigenvectors of Matrices, Similarity Diagonalization of Matrices, Singular Value Decomposition | C            | Second Practice (Choose one from three options) |
| Image Filtering                           | Inner Product of Vectors, 2D Convolution Operation                                                             | D            |                                                 |
| Translation and Rotation of Robotic Arm   | Continuous Translation and Rotation of Vectors in Three-dimensional Space                                      | E            |                                                 |

The project design revolves around the CDIO process while also emphasizing integration with computer software, in line with CDIO Standard 2. During task completion, students' self-initiative, innovation, and team collaboration abilities are mobilized, consistent with CDIO Standard 3.

As evident from the evaluation criteria, students can integrate their theoretical knowledge with practical applications through project-based learning. They utilize their knowledge of linear algebra to explain real-world problems, establish mathematical models, and align with CDIO Standard 7. Completing practical project tasks requires students to work in teams, actively search for literature, design problem-solving approaches, and engage in hands-on experiences, which corresponds to CDIO Standard 8. Students present their group's project accomplishments through presentations, and their performance is comprehensively assessed based on group self-evaluation, peer evaluation, and teacher evaluation, encompassing knowledge, skills, and attitudes. This holistic approach to assessing students' learning outcomes aligns with CDIO Standard 10.

## RESULTS, DISCUSSION, AND ANALYSIS

After the activity, we designed a questionnaire with 12 questions aimed at examining whether students met the requirements of Course Objective 2 during the project-based practical activities and how well they aligned with the expected CDIO standards. The 12 questions and survey results are presented in Table 5 and Figure 1 below.

Table 4 Project Practice Assessment Scoring Criteria

| Evaluation Elements                 | Task 1-4 ( 80 points )   |                                                                         |                                                                  |                         | Task 5 ( 20 points )           |                         |
|-------------------------------------|--------------------------|-------------------------------------------------------------------------|------------------------------------------------------------------|-------------------------|--------------------------------|-------------------------|
|                                     | Completion Status ( 50 ) | Image processing can be explained using linear algebra knowledge ( 10 ) | Image processing is transformed into a mathematical model ( 10 ) | Animation effect ( 10 ) | Completion Presentation ( 10 ) | Team Cooperation ( 10 ) |
| Inter-group Peer Evaluation ( 30% ) |                          |                                                                         |                                                                  |                         |                                |                         |
| Teacher evaluation ( 50% )          |                          |                                                                         |                                                                  |                         |                                |                         |
| Intra-group Self-evaluation ( 20% ) |                          |                                                                         |                                                                  |                         |                                |                         |
| Comprehensive Evaluation            |                          |                                                                         |                                                                  |                         |                                |                         |

Due to the varying number of students in the three classes, Figure 1 shows the distribution of students' responses to each question as a percentage of the total. As can be seen from Figure 1, more than 80% of students in all three classes gave agree or strongly agree responses to all 12 questions, indicating that the project-based practical activities in linear algebra achieved the intended objectives and were positively received by most students.

Table 5 Questions Regarding Project-Based Practical Effectiveness Survey and Corresponding CDIO Standards

|                                                                                                                         |                        |
|-------------------------------------------------------------------------------------------------------------------------|------------------------|
| Q1. Abstract mathematical problems from simple practical issues.                                                        | CDIO Standard 1        |
| Q2. Apply the knowledge of linear algebra learned to solve practical problems.                                          |                        |
| Q3. Independently search for information, combine with learned knowledge, and use software to solve practical problems. | CDIO Standard 2        |
| Q4. Able to establish mathematical models for simple practical problems and solve them.                                 | CDIO Standard 3, 7     |
| Q5. Able to break down encountered problems into smaller, more manageable issues.                                       |                        |
| Q6. Able to face practical tasks with optimism and enthusiasm.                                                          |                        |
| Q7. Able to apply problem-solving methods learned from completing practical tasks to other problem scenarios.           | CDIO Standard 7        |
| Q8. Learned some problem-solving methods from other team members.                                                       | CDIO Standard 3, 8, 10 |
| Q9. Participated in problem-solving and received understanding and encouragement from other team members.               |                        |
| Q10. Able to correctly evaluate one's own work in completing tasks and hopes to do better in the next practice.         |                        |
| Q11. Learned some better methods from the work of other groups.                                                         |                        |
| Q12. Dare to raise reasonable doubts about the views of teachers and classmates.                                        | CDIO Standard 3        |

However, Figure 1 also reveals some detailed issues. For example, a notable proportion of students selected uncertain, disagree, or strongly disagree for Question7, suggesting that some students still have doubts about applying the problem-solving methods learned from completing practical tasks to other problem scenarios.

Additionally, Class 1 had a higher percentage of students selecting strongly agree for all 12 questions and a lower percentage selecting uncertain compared to the other two classes. This difference can be attributed to a specific detail in the organization of activities for Class 1. The main presenter for student showcase activities was randomly selected by the group leader through a lottery, meaning that every student in the group had to prepare a presentation and be ready to participate. This approach resulted in higher student engagement during the showcase activities and, consequently, a better sense of accomplishment among students.

During the showcase activities, students also expressed what they had gained from the practical experience. One group said, "Through this teamwork, we learned how to collaborate with others and how to divide labor and work together effectively. We supported and helped each other, solved problems together, and ultimately achieved good results. Teamwork not only improved our work efficiency but also facilitated our learning and growth. In the two practical sessions, we discovered the widespread applications of linear algebra in real-world problems. Through programming practice, I learned how to use linear algebra to solve practical problems such as image processing and data analysis. These practices deepened my understanding of linear algebra and improved our programming abilities."

Another group stated, "The practical experience enhanced our ability to apply linear algebra knowledge to solve real-world problems. During the experiments, each of us encountered difficulties, but we persevered through discussions and ultimately completed the tasks."

The project-driven practical teaching model of linear algebra presented in this paper aims to provide an evaluation basis for teaching objective 2 in the teaching plan. It is an attempt to

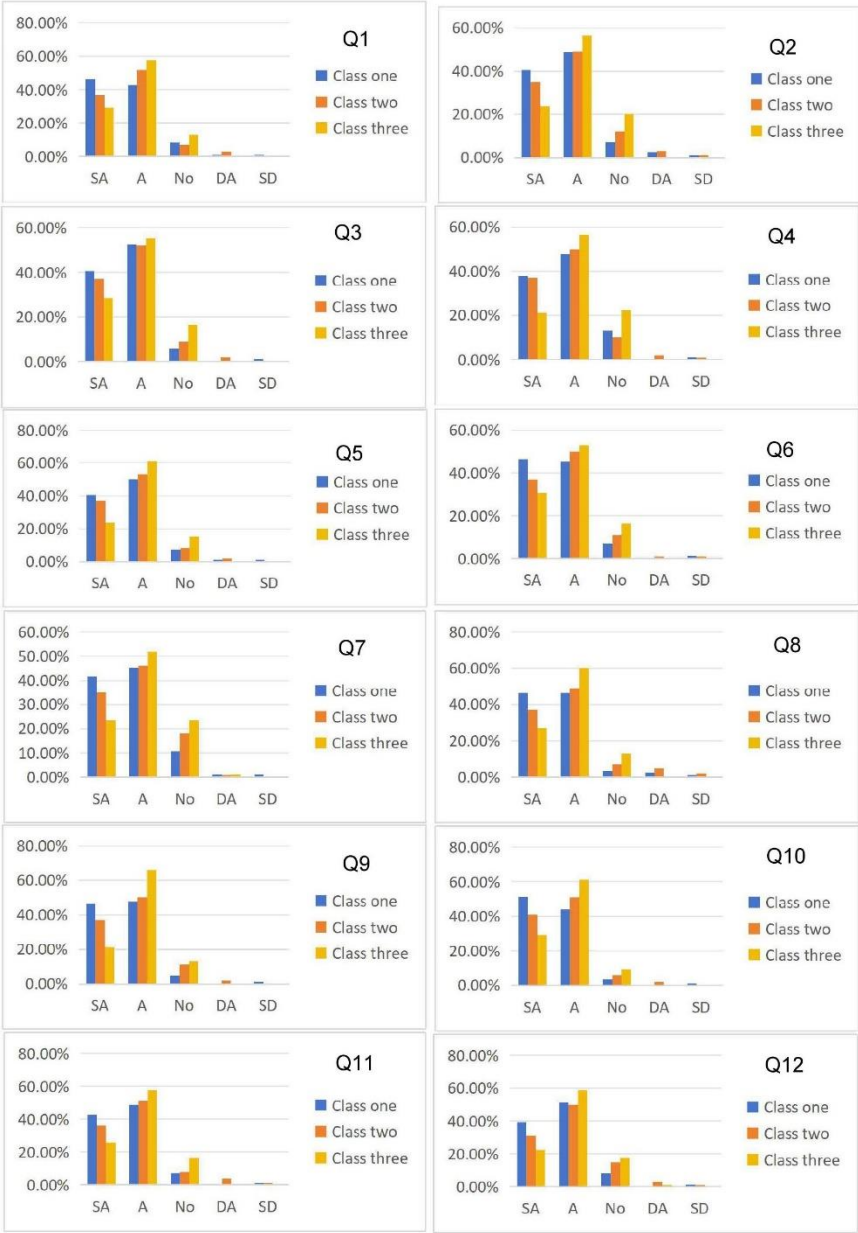


Figure 1 Results of the Student Survey Questionnaire on Project-Based Practical Effectiveness(legend:SA-Strongly agree,A-agree,No-No opinion,DA-Disagree,SD-Strongly disagree)

adopt the CDIO teaching model, limited to a teaching reform experiment within the experimental component of the linear algebra course. Inevitably, some students may not participate enough in project-based practical activities. Therefore, it is suggested that the presenters for the activities could be randomly selected from group members through a lottery, which could improve student engagement. Unfortunately, there was no pre-test survey conducted before the course began, which meant there was no comparison with the data

before the teaching implementation.

## CONCLUSION

This article successfully applies the CDIO teaching model in the field of engineering education to the university-level linear algebra course. Through the design of practical projects and the assignment of practical tasks, students form project groups and collaborate to complete project tasks within a set time frame. The teacher designs corresponding assessment criteria, and group members present the methods and results used to complete their tasks. Practical grades are obtained through student self-evaluation, inter-group evaluation, and teacher evaluation. This project-driven practical teaching model of linear algebra provides support and evaluation basis for achieving teaching objective 2 of the course. The project design and evaluation criteria correspond to CDIO standards 1, 2, 3, 7, 8, and 10. It is an engineering education model that differs from the traditional linear algebra curriculum, which emphasizes theory over practice and application. It is an successfully implemented engineering education methods to the teaching of mathematical theory courses. In the practice of this project-driven practical teaching model of linear algebra, survey questionnaires and student feedback indicate that students not only deepen their understanding and application of linear algebra concepts but also enhance their practical skills, improve their teamwork spirit and communication abilities, and gain an understanding of the application prospects of linear algebra courses. This lays a foundation for future studies in artificial intelligence-related majors.

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# **ETHICS, AI, AND SOCIETY: SHAPING RESPONSIBLE AI ENGINEERS WITH CDIO FRAMEWORK**

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## **ABSTRACT**

This paper describes the development and implementation of a novel course entitled "Ethics, AI, and Society," designed within the CDIO framework to provide ethical education to Artificial Intelligence (AI) graduating engineering students. As AI technologies increasingly permeate various facets of society, the imperative for ethical acumen among engineers comes to the fore. In this regard, the module aims to equip AI engineering students with a holistic understanding of ethical dimensions, societal repercussions, and regulations associated with creating and implementing AI technologies. An interactive pedagogical strategy underpins the module, engaging students with a blend of theoretical discussions and experiential learning fostering a culture of critical thinking, collaboration, and lifelong learning. Building on this foundation, the course thoroughly explores philosophical basis and navigates a spectrum of real-world ethical dilemmas. Topics such as bias mitigation, data privacy, and the broader societal impacts of AI in various domains, including healthcare and economy, are explored in depth. The curriculum is further enriched by a series of diverse guest speakers, each hailing from unique professional background. These experts bring their distinctive perspectives and insights, thereby greatly enhancing the students' comprehension and engagement with the course material. This approach broadens the learning experience and deepens the understanding of the complex interaction between AI, ethics, and society. To ensure that this content leads to concrete learning outcomes and practical skills, the course's design and implementation strictly adhere to the CDIO standards. Preliminary feedback indicates a significant enhancement in students' capacity to tackle complex ethical dilemmas and an increased consciousness of the societal impact of AI. By presenting the course design, delivery methods, and initial outcomes, this paper aspires to serve as a guiding document for educators and institutions aiming to seamlessly integrate ethics into the foundation of AI engineering education.

## **KEYWORDS**

Ethical AI Education, CDIO standards, Engineering Curriculum, Critical thinking, Standards: 1, 2, 3, 7, 8, 11

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## **INTRODUCTION**

The integration of ethics in Artificial Intelligence (AI) is essential due to the complex nature of the field. In this regard this paper introduces a course that merges ethical principles with AI, aligned with the CDIO (Conceive-Design-Implement-Operate) educational framework. Highlighted by Dignum (2018), the ethical dimension is integral to AI development. The curriculum addresses this by incorporating the diverse ethical guidelines in AI, as explored by (Jobin et al, 2019), and the societal implications outlined by (Whittlestone et al. 2019). Governance issues, a crucial aspect of AI ethics discussed by (Cath, 2018), are also covered. This course aims to provide a comprehensive understanding of AI ethics, preparing future engineers to responsibly engage with AI technologies. This paper emphasizes a balanced curriculum that combines traditional engineering fundamentals with hands-on experience and real-world problem-solving (Crawley et al., 2014). In the context of AI, where ethical implications are as significant as technological innovations, the CDIO framework becomes particularly relevant. It ensures that future engineers are proficient in AI technologies and equipped to address the ethical dilemmas these technologies may present.

## **ETHICS IN HIGHER EDUCATION**

Academic institutions are increasingly integrating responsible AI education into their curricula, emphasizing the importance of preparing students for the ethical challenges posed by AI (Saad, M. 2023, Krakowski et al. 2022). This focus on shaping responsible AI engineers underscores the vital role of education in cultivating professionals ready to navigate the ethical complexities of AI in society. (Walsh et al., 2023) underscore the importance of tailored education for healthcare professionals, particularly in medical imaging, recognizing its pivotal role in enhancing transparency and understanding of AI tools. In (Tubella et al., 2024) paper, authors highlight the European Union High-Level Expert Group on AI's recognition of both opportunities and risks in AI. They stress the need for higher education to provide students with technical skills and an understanding of AI's ethical implications aligned with European values.

To this effect, a variety of pedagogical approaches have been employed, with several of them presented and studied by (Aközer et al., 2017) within the field of medical education. In this regard, we first mention the Case-Based Learning (CBL), and the Case-Based Reasoning (CBR) (McSharry, P. E., 2023, Antoniou, J., 2021) which are practical methods that have been used for teaching AI ethics. CBL involves analysing real-world AI ethical dilemmas, fostering discussions, and applying ethical theories to concrete situations. While CBR adapts past cases to new contexts, promoting critical thinking and problem-solving skills. Together, they create an interactive learning environment, equipping students with both theoretical knowledge and practical skills to navigate and address ethical challenges in AI. In addition to CBL and CBR, various pedagogical strategies contribute to a comprehensive AI ethics education (Aközer et al., 2017) and references therein for techniques overview).

## **ETHICS IN AI ENGINEERING**

The ethics of AI is a rapidly evolving field, critically important for engineers and developers. (Hagendorff, 2020) highlights the ineffectiveness of current AI ethics guidelines and stresses the need for more practical and enforceable standards, particularly in the engineering domain (Hagendorff, 2020). (Ryan, 2020) emphasizes the concept of trust in AI systems, advocating

for the development of trustworthy AI through ethical guidelines that ensure reliability and ethical compliance (Ryan, 2020). Furthermore, (Morley et al. 2021) bridge the gap between theoretical ethics and practical AI system design, proposing tools and methods that assist engineers in embedding ethical considerations into AI development (Morley et al., 2021). These perspectives underscore a shift in the AI field towards greater accountability and ethical responsibility, especially in the education and practice of AI engineering (Garrett, Beard, & Fiesler, 2020; Morley et al., 2020).

## COURSE DESCRIPTION

The course content, detailed herein, encompasses a series of specialized topics, each delivered through a two-hour remote interactive learning session by experts in their respective fields. The curriculum begins with an 'Introduction to Ethics in AI', laying a foundational understanding for the ethical considerations critical in AI applications. It progresses to 'Foundations of Ethical Thinking', offering a philosophical base for ethical decision-making in the context of AI. 'Bias, Fairness, and Discrimination in AI' addresses the challenge of creating equitable AI systems, while 'Privacy and AI' focuses on the essential aspects of data privacy. The course also covers 'Autonomous Systems and Accountability', highlighting the responsibilities associated with autonomous AI technologies. Broader societal implications are explored in 'AI, Employment, and Economy', and 'AI in Healthcare, Security, and Warfare', examining the impact of AI on these vital sectors. 'Regulating AI: Governance and Policies' explores the governance frameworks necessary for ethical AI development and usage. The course culminates with a module on 'Case Studies: Ethical Dilemmas in AI Deployments', where practical scenarios are analysed to understand the real-world complexities of AI ethics. The paper underscores how this course, rooted in the CDIO framework, aims to equip learners with a holistic and in-depth understanding of the ethical challenges and considerations in the AI and societal interface.

## SYLLABUS OUTLINE

Table 14. Syllabus outline

| Session | Topic                                    | Content                                                                                                                                                                                                                                    |
|---------|------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1       | Introduction to Ethics in AI             | <ul style="list-style-type: none"> <li>Importance of ethics in AI</li> <li>Historical context: from Asimov's laws to modern dilemmas</li> </ul>                                                                                            |
| 2       | Foundations of Ethical Thinking          | <ul style="list-style-type: none"> <li>Philosophical foundations: utilitarianism, deontology, virtue ethics, etc.</li> <li>The trolley problem and its variants in AI</li> <li>Ethical frameworks and their applicability to AI</li> </ul> |
| 3       | Bias, Fairness, and Discrimination in AI | <ul style="list-style-type: none"> <li>Understanding bias: origins and implications in datasets</li> <li>Algorithms and their inadvertent consequences</li> <li>Strategies to mitigate bias and promote fairness</li> </ul>                |
| 4       | Privacy and AI                           | <ul style="list-style-type: none"> <li>Data collection, consent, and surveillance</li> <li>Privacy-preserving AI techniques</li> <li>GDPR, CCPA, and other regulations affecting AI</li> </ul>                                             |
| 5       | Autonomous Systems and Accountability    | <ul style="list-style-type: none"> <li>Self-driving cars, drones, and decision-making systems</li> <li>Liability and accountability in AI errors</li> <li>The challenge of explainability and interpretability</li> </ul>                  |

|           |                                                  |                                                                                                                                                                                                                                                             |
|-----------|--------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>6</b>  | AI, Employment, and Economy                      | <ul style="list-style-type: none"> <li>• Impact of AI on jobs: displacement and creation</li> <li>• Economic consequences: inequality and new economic models</li> <li>• Reskilling, lifelong learning, and the future of work</li> </ul>                   |
| <b>7</b>  | AI in Healthcare, Security, and Warfare          | <ul style="list-style-type: none"> <li>• Ethical considerations in AI-driven diagnostics and treatments</li> <li>• Surveillance systems, facial recognition, and civil rights</li> <li>• Autonomous weapons and the future of warfare</li> </ul>            |
| <b>8</b>  | Regulating AI: Governance and Policies           | <ul style="list-style-type: none"> <li>• Current international policies and regulations on AI</li> <li>• The role of global institutions, governments, and corporations</li> <li>• Prospects and challenges in AI governance</li> </ul>                     |
| <b>9</b>  | Case Studies: Ethical Dilemmas in AI Deployments | <ul style="list-style-type: none"> <li>• Analysis of real-world scenarios where AI ethics came to the forefront</li> <li>• Discussion of the decisions made and their consequences</li> <li>• Lessons learned and best practices</li> </ul>                 |
| <b>10</b> | Course Wrap-Up and Forward-Thinking              | <ul style="list-style-type: none"> <li>• Group projects: Proposing ethical guidelines for a specific AI application</li> <li>• Exploring the future challenges of AI in society</li> <li>• The role of AI engineers in shaping an ethical future</li> </ul> |

## ALIGNING AI ENGINEERING ETHICS WITH CDIO STANDARDS

The course design and implementation strictly adhere to the CDIO standards (Malmqvist et al., 2019). This alignment begins with Standard 1, connecting AI engineering with real-world ethical and societal considerations. It defines clear Intended Learning Outcomes (Standard 2) that ensure a rounded development of competencies. The integrated curriculum design (Standard 3) merges theoretical knowledge with practical applications, enhancing students' ability to apply ethical principles in tangible scenarios. In line with Standard 7, the course weaves technical knowledge with interpersonal skills development, with a strong emphasis on ethical practices in AI. Active learning is central to the course format (Standard 8), with discussions, case studies, and projects fostering an engaging and participative educational environment. Lastly, the course employs assessment methods (Standard 11) that evaluate students on their CDIO skills, particularly their ability to critically engage with real-world AI challenges and formulate appropriate ethical guidelines.

## ANALYSING STUDENT FEEDBACK

The survey methodology involved a class of 36 students enrolled in the 'Ethics, AI, and Society' course. Of these, 31 students participated in the survey, yielding a response rate of approximately 86%. The survey was administered using Google Forms, ensuring ease of access and efficient data collection. The questionnaire was designed to encompass a mix of binary questions, Likert-scale questions for quantifiable feedback, and open-ended questions to capture detailed qualitative insights, thereby providing a comprehensive evaluation of the course from multiple perspectives.

### **Quantitative analysis**

The survey data focuses on several key aspects of the "Ethics, AI, and Society" course. The numerical ratings section of the survey utilizes a Likert scale ranging from 1 (indicating the worst evaluation) to 5 (representing the best evaluation). The quantitative analysis of the survey data for the "Ethics, AI, and Society" course reveals the following insights:

Table 15. Quantitative analysis of students Feedback

|                                                          | Mean Rating                  | Standard Deviation                                                 | Ratings range                                                                         |
|----------------------------------------------------------|------------------------------|--------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| <i>Effectiveness of Online Lectures</i>                  | Approximately 3.65 out of 5  | 0.79, indicating moderate variability in student responses         | from 2 to 5, suggesting diverse opinions on the effectiveness of online lectures.     |
| <i>Beneficial Nature of Discussions and Case Studies</i> | Around 4.24 out of 5.        | 0.75, showing relatively consistent positive feedback.             | from 3 to 5, indicating generally high appreciation for discussions and case studies. |
| <i>Contribution of Guest Speakers</i>                    | Approximately 4.35 out of 5. | 0.61, suggesting a high level of satisfaction with guest speakers. | from 3 to 5, with most responses skewing towards higher satisfaction.                 |
| <i>Effectiveness of Assessment Methods</i>               | About 4.06 out of 5.         | 0.75, reflecting a fairly consistent positive view.                | from 3 to 5, indicating overall effectiveness but with room for improvement.          |
| <i>Overall Satisfaction with Feedback</i>                | Around 4.06 out of 5.        | 0.75, showing a strong level of satisfaction among most students   | range from 2 to 5, with most students feeling satisfied                               |

**Interpretation and Recommendations:**

*The effectiveness of online lectures* is viewed positively but with notable room for improvement. Engaging delivery methods and interactive content could enhance this aspect.

*Discussions and case studies* are highly valued, indicating their importance in understanding AI ethics. This method should be continued and possibly expanded.

*The guest speakers* made significant positive contributions. Continuation of this approach and possibly involving a broader range of speakers could be beneficial.

*Assessment methods* are generally effective, but exploring varied or additional assessment formats might further enhance learning outcomes.

*Feedback satisfaction* is high, emphasizing the importance of maintaining quality feedback mechanisms.

These insights can be instrumental for the continuous improvement of the course, ensuring it aligns with the CDIO framework and effectively imparts ethical education to AI engineering students.

### ***Qualitative Analysis of "Ethics, AI, and Society" Course: Student Perspectives and Recommendations***

This section of the academic paper presents a qualitative analysis of the survey responses regarding the "Ethics, AI, and Society" course, focusing on the students' perspectives on various aspects of the course.

#### *Engaging Topics and Content Gaps*

*Engaging Topics:* Students expressed diverse interests, with topics like "Bias, Fairness, and Discrimination in AI," "Ethics," and "AI in Warfare" being highlighted. One student notably mentioned, "The ethics topic is a crucial subject that we usually overlook in our studies."

*Content Gaps:* While many students were satisfied, some suggested areas for expansion, such as "understanding more how ethics are translated into laws" and exploring "the evolution of AI and Ethics in 10 years."

#### *Influence on Perception of Societal Impacts*

Students acknowledged a significant shift in their perception of AI's societal impacts. One respondent stated, "It made me look with a different angle for the use of AI in society," illustrating the course's effectiveness in broadening perspectives.

#### *Application to Case Studies*

Responses indicated practical application of learned concepts. For instance, a student described applying "ethical principles and considerations to an AI-powered healthcare system," showcasing the course's impact on real-world problem-solving skills.

#### *Assessment Methods*

Suggestions for improvement in assessment methods varied. Some students were content, calling it "the best way," while others proposed ideas like "anonymous peer review" and "more guest evaluations."

#### *Most Liked Aspects*

The diversity of the course and its interactive nature were frequently mentioned. One student highlighted, "The numerous points of view from different teachers was enriching."

#### *Areas for Improvement*

Recommended improvements included more practical homework, consistent course content, and regular discussion sessions, indicating a desire for deeper engagement and uniformity in course delivery.

### *Additional Comments*

A mix of appreciation and constructive feedback was evident. One student suggested, "The course lessons must be conducted in person," emphasizing the value of face-to-face interactions.

### *Insights and Recommendations for Course Enhancement*

The qualitative analysis of the 'Ethics, AI, and Society' course shows its effectiveness in engaging students with diverse AI ethics topics and enhancing their understanding of AI's societal impacts. While it equips students for ethical decision-making, improvements are needed in content depth, assessment methods, and course consistency. These findings, supported by student quotes, highlight areas for course refinement and its role in advancing ethics in AI engineering education.

### **Synthesis Evaluation of "Ethics, AI, and Society" Course**

The present table summarises the students feedback in key insights and paths to enhanced delivery.

Table 16. Feedback Synthesis

|              | <b>Topic</b>                      | <b>Students Feedback</b>                                                                                                                                       |
|--------------|-----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Key Insights | Content Relevance                 | Predominantly perceived as 'Very relevant' to AI engineering studies, indicating strong alignment with educational objectives                                  |
|              | Preparedness for Ethical Dilemmas | Majority of students feel better equipped to handle ethical issues in AI post-course, reflecting practical efficacy.                                           |
|              | Engagement and Diversity          | Varied topics like bias in AI and AI ethics in warfare captivated student interest, highlighting the course's diverse and engaging curriculum.                 |
|              | Perception Shift                  | Significant impact on students' perspectives regarding the societal implications of AI, fostering a broader and more critical understanding.                   |
|              | Practical Application             | Evident in case studies where students applied ethical principles to real-world scenarios, demonstrating the course's success in merging theory with practice. |
|              | Assessment Methods                | Generally effective but with suggestions for anonymity in peer reviews and more varied guest evaluations.                                                      |
|              | Expand Content Scope              | Integrate emerging topics and deeper explorations into the practical implications of AI ethics.                                                                |



|                                   |                                   |                                                                                                                        |
|-----------------------------------|-----------------------------------|------------------------------------------------------------------------------------------------------------------------|
| <i>Paths to Enhanced Delivery</i> | Increase Interactive Elements     | Encourage more active student participation and discussions to deepen engagement.                                      |
|                                   | Consolidate Course Consistency    | Ensure uniformity in content delivery across different modules for a more cohesive learning experience.                |
|                                   | Refine Assessment Methods         | Incorporate a broader range of evaluation techniques, including anonymous peer reviews and diverse expert assessments. |
|                                   | Strengthen Practical Applications | Further emphasize the application of ethical principles in tangible, real-world situations.                            |

## CONCLUSION

The course "Ethics, AI, and Society" effectively combines ethical theory with practical AI applications, enhancing AI engineering education within the CDIO framework. It has shown success in improving students' understanding and handling of ethical issues in AI. Student feedback indicates strong engagement and learning outcomes, with suggestions for future improvements in content and assessments. This course model can serve as a scalable template for similar educational programs. Ongoing research into the long-term effects of such courses on AI practices and societal impacts is recommended. This educational initiative is a crucial step towards integrating ethical considerations into the rapidly evolving field of AI.

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# AR/VR EXPERIENCES TO SUPPORT AND ENHANCE PILOT PLANT ACTIVITIES

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## ABSTRACT

Monash University Faculty of Engineering, in collaboration with the Monash Pilot Processes Student Team, are creating AR and VR experiences to complement our Membrane Pilot Plant for use in undergraduate education and industry training. We aim combine physical and digital experiences to foster a more autonomous learning environment, preparing students to handle open-ended problems effectively and with greater confidence. The digital experiences are designed to encourage students to apply the CDIO framework, particularly emphasising 'Conceive' and 'Design' stages through virtual problem-solving, before moving on to 'Implement' their new knowledge on the physical pilot plant. The concept can also be applied in reverse, where students undertake physical activities first, followed by implementation of their knowledge in the virtual environment. This paper describes our progress to date in developing and implementing the AR and VR experiences. We present the CDIO approach and standards that have informed our activity development, specifically addressing Standards 5, 7 and 8 to enhance design-implement and integrated experiences, and experiential learning. We discuss two of our digital pilot plant activities in detail: 1) a simple AR activity designed for use on a phone or tablet that is used by all engineering students in their common first year design unit, and by second-year chemical and environmental engineering students in a heat and mass transfer unit, and 2) progress on the development of a more complex VR activity that involves programming a digital twin of the process and will be implemented in a mixed reality headset (HoloLens) to train independent users of the pilot plant. We also present our proposed strategy for assessing the effectiveness of and next steps for this intervention to develop blended lab activities with complementary physical and digital components to provide students with exposure to digital technologies and improve their experience and achievement of learning outcomes associated with the pilot plant lab activities.

## KEYWORDS

Augmented Reality, Virtual Reality, Laboratory, Pilot Plant, Standards 5, 7, 8.

## INTRODUCTION

Augmented Reality (AR) and Virtual Reality (VR) technologies have enormous potential to enhance and support lab activities, particularly those involving pilot scale apparatus which

have limited user scalability and accessibility. The use of AR involves overlaying digital information onto the real-world context, often with live data populating the experience, whereas VR immerses users in entirely virtual environments where data is typically simulated. Both technologies contribute to experiential learning, enabling students to engage with content in dynamic and meaningful ways. AR, VR, and related digital technologies are also increasingly common in industry and society, and students who have access to these tools build critical skills needed for their future careers. (Papanastasiou et al., 2019). Virtual learning environments have also been shown to offer a way to provide students with meaningful, relevant, industrial experience (Maynard et al., 2012).

As well as providing students with authentic and industry-relevant experience and skills, AR and VR can address the challenges of cost and accessibility associated with traditional physical pilot plants. They can substitute, augment and supplement hands-on experience and provide a more inclusive learning environment that is accessible remotely and simultaneously by an almost infinite number of students. For those who do have direct access to the physical apparatus, the option to precede or repeat a physical activity in a virtual environment offers students the opportunity to consolidate their learning from the lab activity and gain a deeper understanding of the underlying principles and processes by allowing them to explore beyond the equipment's physical and safety limits. Activity development using AR and VR can be simplified, and the scope of activities broadened. Instructors no longer need to apply rigorous safety standards and multiple pre-delivery tests of the methods. Students can also develop their own experiences and freely explore scenarios without prescriptive instructions. AR and VR can also be used to simulate online process upsets during an activity, adding authenticity to the experience and building the students' ability to troubleshoot and make informed decisions in a controlled but flexible environment.

The use of AR and VR to enhance and complement pilot plant experiences in tertiary education is increasing, and there are potentially significant benefits to student learning and experience. For example, Díaz et al. (2023) showed that a combination of AR and physical apparatus helped students to understand the concepts and equipment operating procedures for distillation, heat exchanger, and flow apparatus. Motejlek and Alpay (2023) showed that both the VR and multimedia-based activities lead to comparable data retention and student self-efficacy. Carberry et al. (2023) showed that the development of critical practical skills such as basic familiarity, operating and reporting is possible using eXtended Reality solutions.

In 2022, Monash University Faculty of Engineering installed and commissioned the Monash Membrane Pilot Plant (Figure 1). The apparatus is currently used in first-, second-, and third-year coursework units to enable chemical and civil engineering students to apply theory to practice in the real-world context of a common industrial process. To enhance the student experience and provide graduates with necessary digital skills, we are developing AR and VR applications to support and complement the physical pilot plant and enhance the students' capabilities by providing additional pre- and post-lab activities.

## **THE MONASH MEMBRANE PILOT PLANT**

The Monash Membrane Pilot Plant (Figure 1) is a semi-industrial scale membrane-based process capable of removing contaminants or recovering products from water using ultrafiltration and reverse osmosis technologies. The Monash Pilot Plant includes many common unit operations, such as tanks, pumps, and heat exchangers, as well as the membrane modules themselves. The plant also includes many other components that would

be present in an industrial processing plant, such as sensors, valves, safety elements, and an automated control system. This design gives undergraduate engineering students the opportunity to gain practical experience with a real-world process.



Figure 1. The Monash Membrane Pilot Plant

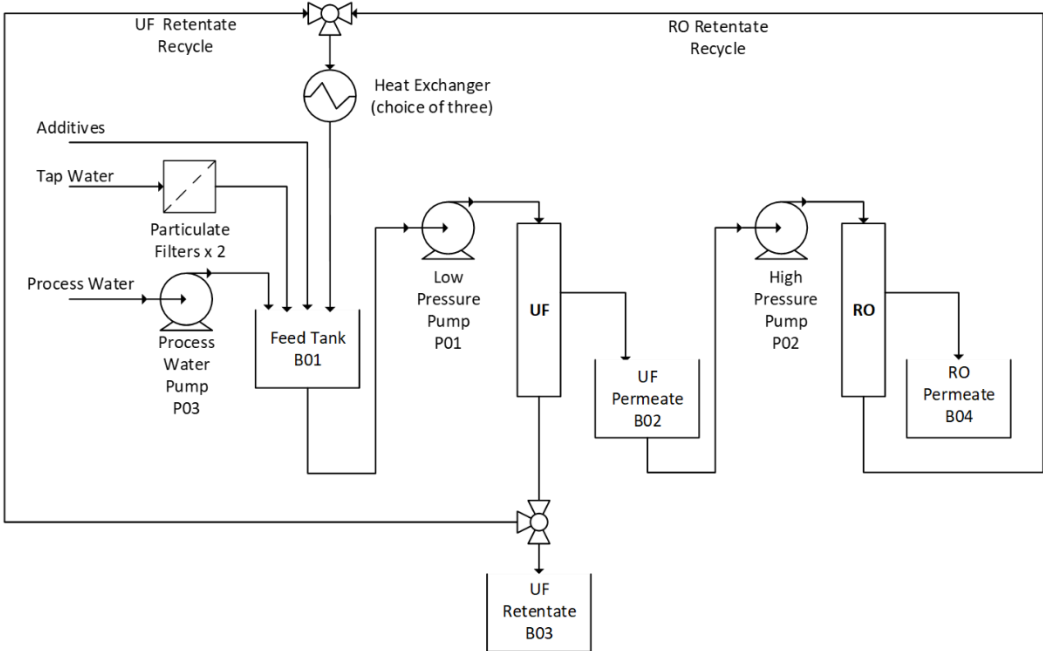


Figure 2. Schematic representation of the integrated UF/RO process

The process consists of two integrated treatment circuits (Figure 2): a low-pressure ultrafiltration (UF) circuit and a high-pressure reverse osmosis (RO) circuit. The process is semi-continuous, with a buffer tank between the two circuits to manage the differences in pressure and flow. The UF circuit is semi-automated, with flow and pressure control loops and an automated clean in place (CIP) backwash system. The RO circuit is controlled manually. Both UF and RO circuits can be run in retentate collection or concentration modes, depending

on retentate recycle back to the feed tank is desired. When the circuits run in recycle mode, the retentate stream gains heat from the pumps. The heat is removed by the heat exchangers to keep the feed temperature constant and minimise viscosity effects on the membrane flux and separation efficiency. There are three different formats of heat exchangers available to remove heat from the UF/RO retentate recycle stream: plate, annular and coil.

The Monash Membrane Pilot Plant is currently used to deliver laboratory activities that enable students to connect theory to practice in eight coursework units in years one, two and three of their undergraduate courses. The activities are designed in a scaffolded manner to encourage students to build upon their prior experience and knowledge of the apparatus when returning to the pilot plant to undertake more complex and open-ended activities later in their courses. In our common first year unit, Engineering Design, students undertake basic orientation and familiarisation activities such as line tracing and development of engineering drawings of the pilot plant process. In second year, students conduct hands on experiments related to core discipline-specific units (heat and mass transfer, thermodynamics) in chemical and environmental engineering by following a laboratory manual with detailed instructions. In third year, students in chemical engineering are given simpler instructions and asked to conduct step testing on the pilot plant control loops to generate data with which they can create simple linear models that represent the pilot plant process dynamics. For each of these apparatus-based activities, we are developing supporting AR and VR activities to enhance the authenticity and learning outcomes for students.

## CDIO APPROACH

We have adopted an iterative process to develop new pilot plant activities based on the CDIO approach. The Director and Monash Pilot Processes Team **conceive** new pilot plant teaching activities by working with unit coordinators and subject matter experts to identify opportunities to use the pilot plant to demonstrate an engineering concept, skill, or competency. The same group then **designs** an activity that enables students to build on and apply their prior knowledge, both theoretical and practical, to meet the learning outcomes of the activity and the unit. We pre-test and **implement** the new activities and collect in person feedback from staff and students with which to iterate and improve the content and delivery in the same semester. We have now been **operating** pilot plant teaching activities for four semesters and have received overwhelmingly positive anecdotal feedback from students and staff. We plan to start systematically generating evidence of our operations in Semester 1 2024 by collecting reflections from students and staff for each of the coursework units in which the pilot plant is used.

Students were and are deliberately involved in every step of the implementation of the pilot plant from commissioning to maintenance and operation to delivery of teaching activities. The original pilot plant process design was based on work conducted by two Master students in 2020. The Monash Pilot Processes (MPP) Student Team assisted with commissioning and are now actively involved in educational development and delivery. This ensures that we are not only adopting the CDIO approach to develop new educational activities, but we are also training students in the CDIO approach. These students will therefore benefit both during their tenure as student team members and pilot plant demonstrators, but also in their future careers.

## ***Pedagogical Frameworks and CDIO Standards***

The adoption of AR and VR in tertiary education aligns with established pedagogical frameworks that emphasize interactive and student-centred learning. We typically take a constructivist approach and apply experiential learning theory as well as CDIO Standards 5, 7 and 8 when developing our AR and VR pilot plant activities. Both frameworks highlight the importance of students actively participating in their learning through simulations, projects, and hands-on activities.

The constructivist approach emphasizes active engagement and hands-on experiences and shows strong evidence of effectiveness in engineering education (Soliman et al., 2021) and aligns well with CDIO Standard 5, which focuses on design-implement experiences. Both stress the importance of students actively participating in the process of developing products, processes, systems, and services. AR and VR applications help facilitate this constructive learning process by providing students with simulated environments and interactive elements. Additionally, it resonates with CDIO Standard 7, promoting integrated learning experiences that combine disciplinary knowledge with personal and interpersonal skills. The constructivist approach also supports CDIO Standard 8, as it inherently fosters active learning through engagement in manipulative, analytical, evaluative, and applicative activities.

Experiential Learning Theory (ELT) underscores the importance of learning through reflection on experiences (Kolb et al., 2001) and has been successfully applied to the use of AR to enhance laboratory activities. For example, Abdulwahed and Nagy (2008) applied Kolb's experiential learning cycle to develop virtual lab preparation sessions that were shown to enhance the learning outcomes of students in the experimental group in comparison to the control group. ELT aligns with CDIO Standard 5, emphasizes learning through concrete experiences and active experimentation in design-implement experiences. It supports CDIO Standard 7 by combining disciplinary knowledge with personal and interpersonal skills. Experiential Learning Theory aligns with CDIO Standard 8 by promoting active engagement and reflection as integral parts of the learning process. Many of our AR and VR activities also draw upon previous experience of CDIO implementation for similar activities at other institutions, as presented in the following section.

## **PILOT PLANT DIGITAL ACTIVITY DEVELOPMENT**

### ***AR Experience***

The AR experience is a simple offline experience that has been programmed in Vuforia Studio (PTC, 2024) and is accessible by students via the Vuforia View app on their phone or tablet. The app allows students to view a scalable 3D render of the pilot plant overlaid onto their current physical environment. They can 'walk around' the pilot plant, zoom in, and select items to toggle text box popups (if enabled) with more information about that part of the pilot plant. Undergraduate engineering students use the AR experience up to two times in their course, depending on their discipline.

In our common first year unit, Engineering Design, students undertake basic orientation and familiarisation activities such as line tracing and development of engineering drawings of the pilot plant process. Cheah (2021) reported that students were able to effectively learn how to



line trace and draw a P&ID based on a physical pilot plant. In our activity, due to the large cohort size, we provide students with an AR version of the pilot plant (Figure 3) for the same purposes.

We also provide the same AR experience to second year students undertaking an activity to assess the steady state heat transfer rate and overall heat transfer coefficient of two different heat exchangers on the pilot plant. Students are required to complete two pre-lab activities using the offline AR experience: 1) complete a P&ID labelling exercise to ensure they are familiar with the parts of the pilot plant that are relevant to the activity they will complete 2) complete a safety quiz based on the AR experience and a short supporting video. The use of AR and VR in this scaffolded manner and for safety purposes has been previously reported to be successful (Katerina Yang, 2020) and we have observed comparable results. Students who have completed the first-year activity are able to complete the second-year activities more quickly and with greater accuracy, and they have a greater understanding of and appreciation for the safety considerations of operating the pilot plant.

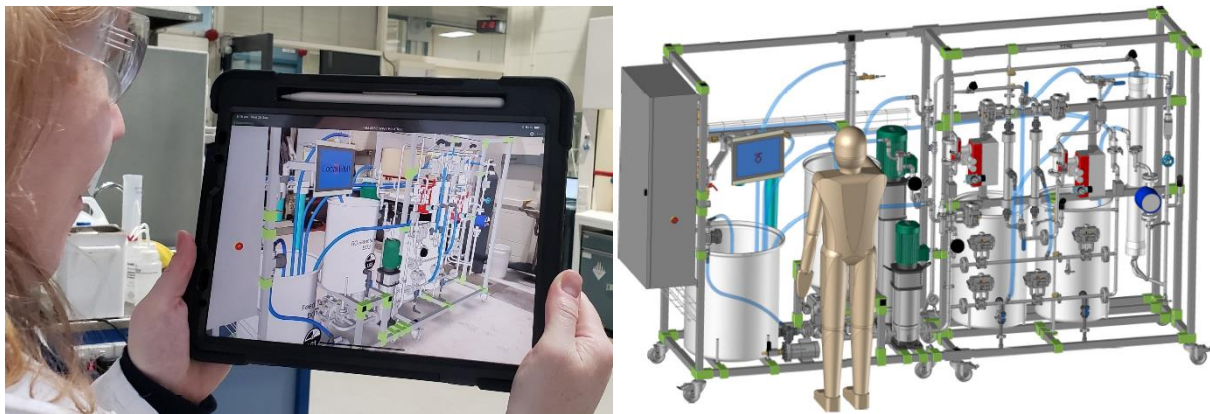


Figure 3: The AR Experience in Vuforia View, and the 3D render of the pilot plant

### **VR Experience**

The VR experience is being developed by Monash Pilot Processes for operator training and student activities. It is an immersive simulation of the pilot plant and its surrounding environment. This program is intended for use with mixed reality devices, such as the Microsoft HoloLens, where the user is part of in the virtual environment, receiving and responding to in-experience instructions and online or simulated responses based on their interaction with the model. The VR experience can also be run on a PC as an AR experience in cases of user preference or low availability of VR hardware. The instructions displayed to the user at a given time are determined by a state machine which tracks the simulation as it is computed. Currently this state machine is manually designed, but future work aims to leverage the knowledge graph to streamline the creation of training experiences.

We are using the Unity Real-Time Development Platform with Vuforia Engine for virtual / augmented reality functionality. Previous applications of Unity for AR/VR following the CDIO approach have recently been reported (Ivanna Sandyk, 2023). We use Protégé for ontology definition, and a Python script to generate the individual nodes and relationships of the graph which adhere to this ontology. The simulation underpinning the experience operates on a knowledge graph which encapsulates information about the plant for use in different contexts. The knowledge graph contains information about the different devices (pumps, tanks, sensors, valves, heat exchangers) which are part of the plant. Knowledge graph-based simulation was

chosen as it explicitly separates the representation of the structure of the process from how it is to be modelled. This allows more freedom in application than if the two were coupled. For example, an activity might involve substituting different membrane models to compare their ability to capture phenomena seen in membrane separations.

The experience is currently configured as an operator training experience, the user can carry out a set experimental procedure, following instructions as they are given by the program. Figure 4 shows the simulation environment and example instructions that the user is given to operate the model pilot plant. Rather than being an authored sequence of steps, the behaviour of the simulation is the result of a self-consistent set of rules, with the intent that the user be able to push the limits of the simulated process as bounded by those rules, approaching, and even surpassing the capabilities of the physical pilot plant. More open-ended educational activities can be designed by taking advantage of this. For example, tasking students with achieving a given yield despite malfunction in a particular sensor, requiring them to draw on a more holistic understanding of the process and the phenomena at play. This will enable students to move towards CDIO Standard 5.

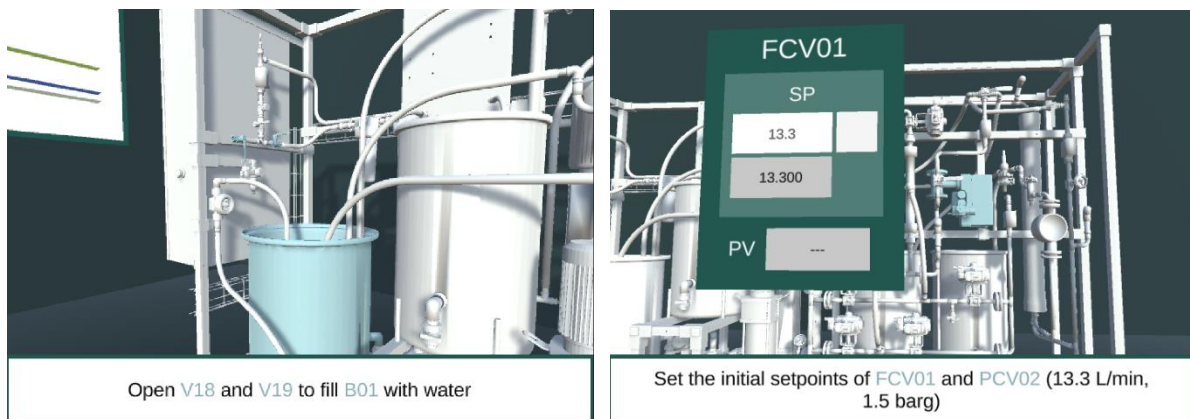


Figure 4: The VR Experience in Vuforia Engine showing text instruction and highlighting of the relevant parts of the simulation for user interaction.

## RESEARCH PLAN

The past two years have been focussed on commissioning the physical pilot plant and developing the AR and VR experiences. We are now operating and ready to implement and our interventions and design methodologies and methods to collect evidence of their efficacy.

We believe that the implementation of AR and VR experiences to support and complement pilot plant labs improves the student experience and achievement of intended learning outcomes. We aim to show that students' achievement of the learning outcomes (as indicated by their unit grades) is positively affected by our interventions by comparing 2024 student grades with those of past cohorts in the same activities in the same units. CDIO literature indicates that this may be the case (Jörg Schminder, 2019). We also aim to show that student cognition develops towards higher levels as they undertake the scaffolded physical and digital Pilot Plant activities by analysing student and staff reflections for students at different year levels.

We are constructing a mixed methods research design to collect evidence to test the above hypotheses including:

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- Pre- and post-analysis of student reflections on their experience in pilot plant activities
- Multi-year, cohort specific analysis as well as generalised year level analysis, including grade analysis to determine the impact on student performance
- Standard university-run student satisfaction surveys, which include quantitative and qualitative questions related to the standard of the unit.

We already know that the Pilot Plant improves the undergraduate student lab experience based on early, informal student feedback. We will develop and validate tailored pre- and post-survey instruments and reflective activities to collect the data. The instrument will include several Likert-style questions to probe specific points of interest, as well as a reflective section that will be used to track the development of student learning as indicated by the students' use of Taxonomy words in their reflections, or by derivation of the Taxonomy levels from the students' reflections. We will also be looking at the scaffolded activities and student development through the year levels through a systems thinking framework whereby students develop the ability to make sense of complex situations of scenarios, including industrially relevant wicked problems, in terms of a structured whole consisting of related internal and external elements.

We are currently in the process of refining the methodology and combination of methods and relevant instruments that will be applied in this research and will shortly be applying for ethics approval to enable us to validate the instruments into the Pilot Plant physical and digital activities in Semester 2 2024, and conduct comprehensive evaluation of our interventions in 2025.

## **CONCLUSION**

AR and VR experiences can significantly improve accessibility and learning outcomes associated with practical activities in undergraduate engineering courses. Monash University Faculty of Engineering are developing digital activities using the CDIO approach to enhance and complement our physical pilot plant activities, which are scaffolded across the first three years of the undergraduate engineering course. We have implemented AR experiences based on an offline 3D model of our pilot plant for first- and second-year students to provide orientation and familiarisation with the equipment, safety training prior to hands-on activities, and the opportunity to apply theory to practice in creating and interpreting engineering drawings. Anecdotal feedback indicates that lab activities where physical apparatus is supplemented by an AR experience, either prior to or post lab, deliver an improved student experience. We are currently designing an immersive VR experience with a comprehensive dynamic model of the pilot plant. The VR experience will enable user interaction and facilitate improved access to the equipment for training and coursework activities, including the ability to operate scenarios that are beyond the physical or safety limitations of the pilot plant itself. The next steps for this project are to complete the activity design and implementation, and to collect evidence of the efficacy of our project to improve intended learning outcomes for students using the pilot plant and its associated AR/VR experiences.

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# ENHANCING CONCEIVE-DESIGN COMPETENCIES IN PART-TIME ENGINEERING EDUCATION: ESPRIT'S APPROACH TO CDIO

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## ABSTRACT

This communication examines the adaptation of the CDIO framework for evening engineering courses at ESPRIT, tailored to senior technicians holding a Bachelor of Engineering degree. These professionals enroll in the program to pursue the National Diploma in Engineering over an extended four-year period, compared to the three-year day courses. The evening students bring substantial experience in the 'Implement' and 'Operate' components of CDIO but often need further development in 'Conceive' and 'Design - a point for improvement highlighted by several human resources managers in the engineering industry. Integrating 180 ECTS (European Credit Transfer and Accumulation System) into this longer duration, the curriculum is customized to enhance these skills. The primary goal is to cultivate graduates who are technically knowledgeable and skilled in innovation, problem-solving, and the practical application of engineering principles. The evening courses aim to align with the same educational objectives and standards as the day courses, despite different student profiles and timelines. The paper outlines the strategic implementation of these courses, emphasizing how the tailored approach effectively bridges the gap in Conceive and Design skills, thereby equipping students with the comprehensive CDIO skill set expected of a graduate engineer.

## KEYWORDS

Skill Gap Analysis, Conceive-Design Skills, Curriculum Customization, Part-Time Engineering Program, Standards: 1, 2, 5, 7, 8, 11.

## INTRODUCTION

The imperative of enhancing employability in engineering education at universities depends on aligning curricula with evolving industry needs. Rapid technological advancements necessitate engineers who are adept with current knowledge and skills to address industry challenges (Gope & Gope, 2022). Universities must adapt their curricula to prepare graduates for immediate integration into the workforce and societal contribution. This adaptation involves embedding necessary skills into engineering programs and offering experiential learning for practical experience (Rouvrais, Remaud, & Saveuse, 2020). The goal is a curriculum that meets enterprise demands and equips students for successful industry careers (Manna, Joyce & Nortcliffe, 2023).

The traditional focus on technical skills is insufficient; employers now seek graduates with a blend of technical, interpersonal skills, and practical experience. This shift necessitates curricular changes to encompass communication, teamwork, problem-solving, and design thinking, coupled with enhanced industry collaboration to ensure relevance of skills and knowledge (Stiwne & Jungert, 2010). Addressing this challenge will yield highly employable graduates capable of significant organizational contributions (Stiwne & Jungert, 2010).

For professional engineering students, it's essential to keep pace with the rapidly changing skills needs of industry. The field's constant flux with new technologies and challenges underlines the need for ongoing skill updates. Their learning path should build on existing knowledge while engaging in advanced activities for career progression (Manna, Joyce & Nortcliffe, 2023).

The CDIO framework, focusing on conceive, design, implement, and operate, is central to engineering education. For part-time students, emphasizing the 'conceive' and 'design' aspects is vital, leveraging their technical foundation and the use of generative AI tools to speed up technical production. Generative AI facilitates tasks like code review, allowing focus on high-level design and conception.

Problem-based learning (PBL) and design projects are effective in enhancing 'conceive' skills. PBL confronts students with real-world problems, developing creativity, idea evaluation, and effective communication (Gope & Gope, 2022). Design projects and reviews further refine these skills, encouraging critical thinking, alternative evaluation, and stakeholder communication (Zou, Liu, Yhang & Han, 2017).

This approach intersects with objectives to boost employability, apply PBL, personalize learning, and develop CDIO skills. It aims at a student-centered model, focusing on skill and career development and heightened engagement with the learning process. Our methodology is structured in three sections: building on professional students' existing knowledge, presenting our aligned working method, and highlighting the benefits of these methods for competence and motivation. The conclusion will summarize undertaken actions and the anticipated outcomes.

## **WHY AND HOW BUILDING ON THE EXISTING KNOWLEDGE OF PROFESSIONAL STUDENTS**

When designing learning path for professional engineering students, it is crucial to build on their existing knowledge, to meet their specific needs and career goals and to ensure their engagement with the learning process (Duckett, 2010). This process requires a thorough understanding of the knowledge and skills that professional students already possess, which can be achieved through a needs assessment that includes surveys, interviews, or focus groups. Once this information is gathered, course content can be aligned with industry needs and job roles, ensuring that professional students are learning the skills that are most relevant to their careers (Arsad & Idrus, 2019). Incorporating emerging technologies and trends into course content is also important, as this can help professional students to stay up to date with the latest developments in their field. Case studies, research projects, and guest lectures from industry experts constitute effective ways to incorporate emerging technologies into course content. Providing opportunities for hands-on learning is also essential for professional engineering students, as they typically have extensive experience in the industry.

Flexible learning options are also essential for professional engineering student's classes. Online courses, hybrid courses, and self-paced learning modules can all be effective ways to provide flexible learning options that accommodate the needs of professional students.

Providing opportunities for peer-to-peer learning can help to create a collaborative learning community that supports the professional development of engineering students. Group projects, discussion forums, and networking events are effective ways to facilitate peer-to-peer learning and build a sense of community among professional students. Universities can use peer-to-peer teaching to allow students to share their expertise with their peers. This can help students to reinforce their own knowledge and skills, identifying emergent skills, while also providing support to their peers (Jambari, Razali, Seth@Noh, Ahyar, Pairan, Ahmad & Osman, 2019).

The flexibility of the process and personalizing learning experience allow students to focus on developing advanced skills, such as critical thinking, problem-solving, and collaboration. Additionally, innovative teaching methods can provide students with a more engaging and interactive learning experience, helping to keep them motivated and engaged throughout the course (Solari, Vizquerra & Engel, 2019).

## **DESCRIPTION OF THE LEARNING MODEL AND IMPLEMENTATION**

For professional students, the engineering curriculum lasts four years, with a global number of ECTS expected to be achieved by students equal to 180. The breakdown is 40 credits for each of the first three years of studies, 30 credits for the fourth year and the last 30 credits attributed the end of studies project. Each of the first three years includes a capstone project designed to professionalize and apply courses contents.

To implement the "build on their existing knowledge" approach, we focused on restructuring the capstone project, where students are traditionally invited to develop technological solutions, aligned to the technical and scientific contents insured during courses. Projects specifications including technical and scientific requirements are traditionally provided by the academic tutors with limited insight on developing the 21 century skills, namely: critical thinking, creative thinking, communicating, and collaborating.

The main constraint encountered by the tutors lies in the heterogeneity of the professional profiles, with different levels of mastery of the technical components. This results in asynchronization between members of the same team in terms of progress, mastery and quality of the final deliverable. A decreasing motivation of some team's members with advanced mastery of technical concepts, due to the weakness of the challenge compared with the professional activities and achievements.

Aligned to the 'build on their existing knowledge' principle, the objective of this work is providing an implementation of the capstone project ensuring better alignment with the professional learners needs in terms of complementary training within an inclusive environment enhancing collaboration and communication. We added to the learning path a module entitled 'professional project', lasting 10 hours, with work realized by teams of 6 members focusing on developing details of the capstone project and tasks repartition. Acceptance of the project is conditioned by its degree of innovation and relevance in terms of solving a real problem and conceiving and designing a solution. Proposed projects are assessed by senior industry



professionals, to measure the degree of alignment with business requirements in terms of conception and design.

According to the CDIO framework, the learning process is completed by inviting students to develop or build the final product or service, aligned with the conceive and design operations results adopted and approved during the professional project module. In addition to technical skills, this second part focuses developing real word managerial skills, namely: project management, tasks allocations, workgroups, timelines, supported by the advanced expertise of professional students.

Finals realizations are assessed following a competency grid inspired from the CDIO syllabus 3.0. For the following the major section of the assessment grid:

- Fundamentals knowledge and reasoning
- Personal and professional skills and attributes
- Interpersonal skills: collaboration, teamwork and communication
- Conceiving, designing implementing and operating systems in enterprise Societal and environmental context-The innovation process.

Criteria under sections are parametrized with reference the type of deliverable of the project with scores reflecting originality of the final product, and excellence of the managing process.

## **ADVANTAGES OF THE PROPOSED REFORME**

### ***Professional Project***

By integrating the course "Professional Project" in the curricula, we build a learning experience where professional students can effectively define a personalized learning model. Through this reform, we are trying to emphasise the following components:

**Personalized learning:** By allowing students to define their own project objectives, universities can provide a more personalized learning experience that is tailored to each student's individual needs and career goals. Personalized learning enhances conceiving and design skills by stimulating autonomy, goal-setting, adaptability and meta-reflective thinking, creating strong foundations for generating original ideas and producing well-aligned designs.

**Adaptative and collaborative learning:** By allowing students to work on a project that is relevant to their personal and professional goals. By allowing students to work on their professional project in a collaborative environment, universities can facilitate peer-to-peer learning and provide students with opportunities to learn from each other. This learning environment help students to develop their conceive and design skills by allowing them to share ideas, provide feedback, and learn from their peers.

**Real-world experience:** By requiring students to work on a real-world project, universities can provide students with valuable experience. The resulting learning environment help students to build their professional portfolio and prepare for their future career. Conception and design skills are particularly addressed, given expectations of the introduced course in terms of proposed project and solution originality.

Reflection and peer reviewing: Universities enhance conceptualization and design abilities in students by facilitating reflective practices and encouraging peer assessment. These approaches enable learners to recognize weaknesses and devise methods for improving targeted areas, ultimately refining their skill sets. This iterative process strengthens their problem-solving capabilities and promotes continuous growth throughout their academic journey.

Mentoring or Teaching Assistantships: Professional students can gain valuable experience and solidify their understanding of the material by serving as mentors or teaching assistants for lower-level courses. Mentoring or teaching assistantships substantially improve conceiving and design skills by offering direct observations, promoting cross-disciplinary dialogue and addressing challenges creatively.

### ***Assessment of the professional project by senior professionals***

Benefits of integrating seniors in the assessment of the “professional project” are as follows:

Expert feedback: Senior professionals in the discipline have extensive experience and expertise in the field, which can provide valuable feedback to students on their professional project. The feedback helps students to identify areas for improvement, refine their skills, and develop their knowledge and understanding of the discipline.

Real-world perspective: Senior professionals in the discipline can provide a real-world perspective on the professional project, helping students to understand how their work can be applied in a practical context. The feedback helps students to develop their skills and knowledge in a way that is relevant to their future careers.

Networking opportunities: the intervention of senior professional provides students with opportunities to network and build relationships with industry leaders. This can help students to build their professional network and increase their chances of finding employment or internship opportunities in the future.

Credibility and recognition: the feedback of senior professionals in the discipline provide students with credibility and recognition for their work.

Quality assurance: the feedback of senior professional ensures that the project meets high standards of quality and relevance. The assessment model helps students to develop their skills and knowledge in a way aligned with industry expectations and best practices.

### ***Competency-based assessments:***

Here are some advantages of competency-based assessments:

They are authentic and meaningful: Competency-based assessments measure learners' ability to apply their knowledge and skills to real-world problems.

They are learner-centred: Competency-based assessments focus on the learner's individual needs and strengths. This allows learners to demonstrate their skills and knowledge in a way that is most appropriate for them.

They are flexible: Competency-based assessments can be adapted to meet the needs of different learners and learning environments.

They can be used for formative and summative assessment: Competency-based assessments can be used to provide feedback to learners on their progress, as well as to make summative judgments about their achievement.

## **CDIO COMPLIANCE**

The adoption of the CDIO framework in ESPRIT's evening engineering courses addressed the skill gap in design and implementation. This approach demonstrates a strategic application of the CDIO standards, meeting specific educational needs and enhancing the skill set of graduates. In the sequel, we describe the implementation of CDIO Standards in the evening courses, focusing on bridging the skill gap in Conceive and Design.

### ***Alignment with CDIO Standards:***

*Adherence to Standard 1 (The Context):* The program's focus on developing 'Conceive' and 'Design' skills in students, who already possess experience in 'Implement' and 'Operate', aligns with Standard 1. This standard emphasizes the importance of covering all aspects of the product and system lifecycle - Conceive, Design, Implement, Operate - within the context of engineering education (CDIO Standards, 2023).

*Conformity with Standard 2 (Learning Outcomes):* The curriculum's focus on enhancing innovation, problem-solving, and practical application of engineering principles aligns with Standard 2. This standard calls for specific, detailed learning outcomes for personal and interpersonal skills, and product process system and service building skills, in line with program goals.

*Consistency with Standard 5 (Design-Implement Experiences):* The strategic implementation of the curriculum, with an emphasis on enhancing 'Conceive' and 'Design' skills, is consistent with Standard 5. This standard advocates for the inclusion of multiple design-implement experiences in the curriculum. By customizing the curriculum to focus on areas where students need further development, the program ensures that students engage in a balanced range of activities, covering all stages of the engineering process.

*Alignment with Standard 7 (Integrated Learning Experiences):* The evening courses are designed to provide integrated learning experiences, aligning with Standard 7. This standard emphasizes the importance of pedagogical approaches that enhance the learning of disciplinary knowledge along with personal and interpersonal skills. By bridging the gap in 'Conceive' and 'Design' skills, the program provides an integrated learning experience that combines theoretical knowledge with practical skill development.

*Adherence to Standard 8 (Active Learning):* PBL is the main approach to course delivery at ESPRIT School of engineering, particularly in the conception and design components in the context of the evening courses. This strategic pedagogical adoption adheres to Standard 8, which focuses on active and experiential learning methods. The evening courses are structured to engage students in active problem-solving and design tasks, reflecting the standard's emphasis on active engagement in the learning process.

*Adherence to standard 11 (Learning assessment):* The evaluation methods employed in the PBL evening courses, align with CDIO Standard 11, which emphasizes the assessment of student learning in various skills along with disciplinary knowledge. In this approach:

- **Report Preparation:** Students prepare detailed reports on their projects, which improve their ability to document and articulate technical content, a key component of disciplinary knowledge.
- **Peer Review:** The peer review process engages students in critical analysis and feedback, enhancing their interpersonal skills and ability to evaluate engineering work critically, in line with the CDIO's emphasis on collaborative learning and self-improvement.
- **Presentations and Defence:** Presenting and defending their projects before a jury cultivates students' communication skills and their ability to articulate and justify their design choices, aligning with CDIO's focus on effective communication in professional settings.

The evening engineering courses at ESPRIT demonstrate a comprehensive and thoughtful alignment with the CDIO framework, particularly in addressing the unique needs of senior technicians. The program's focus on enhancing 'Conceive' and 'Design' skills, while leveraging students' existing strengths in 'Implement' and 'Operate', ensures that graduates are equipped with the complete set of skills and competencies expected of an engineering professional as outlined in the CDIO Standards.

## **CONCLUSION**

This work presents the implementation of a training model for professional students in ESPRIT's evening engineering course, aimed at enhancing conceive and design skills within the CDIO framework. The model addresses the career development needs of professionals with diverse expertise and profiles. It caters to two groups of bachelor's degree holders: those seeking career change or progression in a new field and experts aiming for career advancement. The approach includes a "professional project" module for ideation, design, and conception, followed by an "integration project" module. Projects developed in groups are assessed by industry experts to ensure they meet industry standards. This method responds to the challenge of maintaining engagement among experienced professionals by leveraging their expertise to elevate project quality and align skills with labor market demands. It emphasizes lifelong learning and career advancement. The implement and operate components of the CDIO approach are addressed through the project module, promoting self-training to meet industry needs. The model was implemented in the second-year class of the computer engineering cycle this academic year, with results to be discussed in a future article.

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# IMPLEMENTATION OF CDIO SKILLS INTO THE MECHATRONICS AND ROBOTICS MAJOR

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## ABSTRACT

This research paper focuses on the implementation of CDIO skills corresponding to learning outcomes within the analyzed curriculum of the Mechatronics and Robotics Major. The study aims to identify the extent of alignment between CDIO skills and learning outcomes, providing recommendations for further enhancing the integration of these skills into the curriculum. The study commences by identifying the key CDIO skills pertinent to the mechatronics and robotics domain. These skills encompass Conceiving, Designing, Implementing, and Operating, namely the holistic nature of engineering education. A thorough analysis of the learning outcomes of the mechatronics and robotics curriculum is then conducted to determine the extent of alignment with the identified CDIO skills. A comprehensive review of relevant literature related to CDIO skills, learning outcomes, and mechatronics and robotics education was conducted. In the context of mechatronics and robotics education, several studies have been reviewed to investigate the impact of CDIO-based curriculum on student learning outcomes. The mechatronics and robotics major curriculum was analyzed to identify the specific learning outcomes associated with each course. The identified learning outcomes were mapped to the corresponding CDIO skills, ensuring that the curriculum provides opportunities for students to develop these essential skills. Additionally, the curriculum incorporates hands-on laboratory activities and design projects, providing students with opportunities to apply their knowledge and skills to real-world problems. (Atayeva, Sh. Garlyyeva, Ch. Orazov, Y. Innovative Approach to Training Sustainable Engineers) Recommendations are provided for strengthening the alignment between CDIO skills and learning outcomes, ensuring that mechatronics and robotics graduates possess the necessary skills to thrive in the challenging and dynamic world of engineering. The results of this study can serve as a guide for further enhancing the integration of CDIO skills into the curriculum.

## KEYWORDS

CDIO Skills Implementation, Mechatronics and Robotics, learning outcomes, curriculum analysis, CDIO Standards: 2, 3, 4

## **DEVELOPMENT OF MECHATRONICS AND ROBOTICS: A JOURNEY THROUGH TIME AND TOWARDS THE FUTURE**

### ***Current Trends and Prospects in the Field of Mechatronics and Robotics***

In the 21<sup>st</sup> century, mechatronics and robotics are at the forefront of technological innovation, impacting various industries, from manufacturing and healthcare to transportation and entertainment. One prominent trend is the rise of collaborative robots, or cobots, designed to work alongside humans. These robots enhance efficiency and safety by sharing spaces and tasks with human workers.

Advancements in artificial intelligence and machine learning are driving the development of intelligent robots capable of learning from experience. These robots can adapt to changing conditions, make decisions, and perform tasks beyond their initial programming. The fusion of robotics with AI is opening new possibilities in areas like autonomous vehicles, drone technology, and smart homes.

The Internet of Things (IoT) is another influential trend in mechatronics. Connecting devices and systems through the internet allows for real-time data exchange and remote control. In robotics, this translates to improved monitoring, diagnostics, and maintenance of robotic systems. Smart factories, powered by interconnected mechatronic systems, are transforming the landscape of industrial production.

Looking ahead, the prospects for mechatronics and robotics are tantalizing. As technologies converge, we can anticipate the development of robots with enhanced sensory capabilities, natural language processing, and the ability to collaborate with each other autonomously. Robotic systems will likely play pivotal roles in addressing societal challenges, such as healthcare support for an aging population and disaster response.

In conclusion, the journey of mechatronics and robotics from historical roots to contemporary trends showcases the remarkable evolution of human-machine interaction. From the mechanization of the Industrial Revolution to the intelligent and collaborative robots of today, the field continues to push boundaries. As we stand on the cusp of a new era, marked by AI, IoT, and interconnected systems, the future of mechatronics and robotics promises unprecedented advancements that will shape the way we live and work.

## **INTEGRATION OF CDIO SKILLS INTO THE MECHATRONICS AND ROBOTICS EDUCATIONAL PROGRAM: A FRAMEWORK FOR EXCELLENCE**

### ***A Phased Approach to CDIO Integration in Mechatronics and Robotics***

We have created a model framework for implementing CDIO principles into the Mechatronics and Robotics major curriculum at our university. This framework outlines a six-year plan (2023-2029) divided into five distinct phases, each with specific actions designed to achieve a successful integration of CDIO.



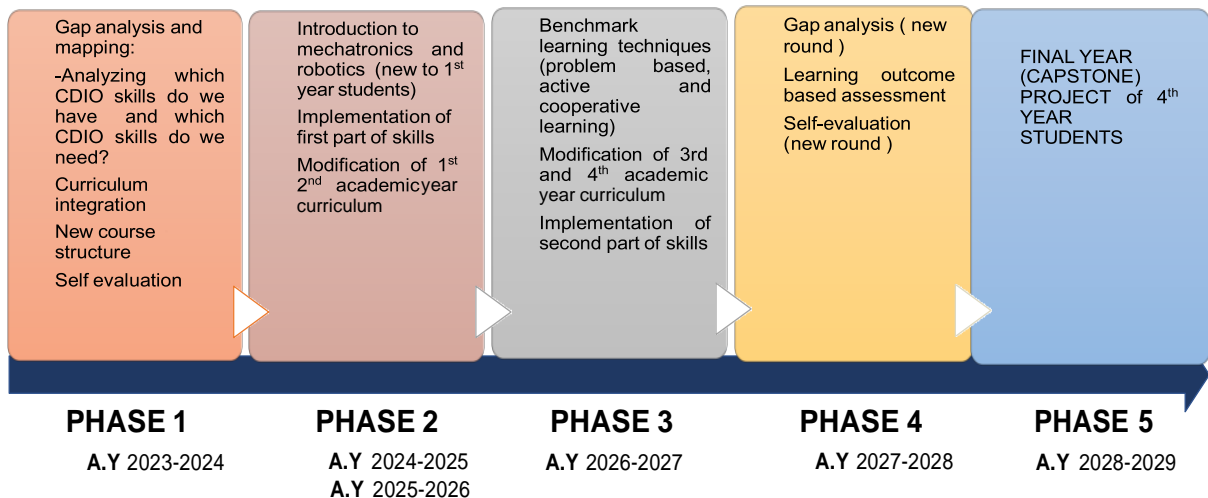


Figure 1. Model framework for Implementation of CDIO

#### *Phase 1 (Academic Year 2023-2024)*

The first phase focuses on laying the groundwork for CDIO integration. This includes activities such as a gap analysis and benchmark assessment to identify areas where our current curriculum aligns with CDIO skills and areas where improvement is needed. We will also conduct a review of learning outcomes to ensure they are aligned with CDIO principles.

#### *Phase 2 (Academic Years 2024-2026)*

It centers around curriculum modification and the implementation of the first part of the CDIO skills identified in the gap analysis. We will modify the 1<sup>st</sup> and 2<sup>nd</sup> academic years curriculum to begin incorporating CDIO skills. This may involve developing new courses or revising existing ones to include elements of Conceiving, Designing, Implementing, and Operating (CDIO).

#### *Phase 3 (Academic Year 2026-2027)*

Phase 3 focuses on further curriculum development. We will modify the curriculum of the 3<sup>rd</sup> and 4<sup>th</sup> academic years to ensure a comprehensive integration of CDIO principles throughout the program. Additionally, we will begin implementing the initial set of identified CDIO skills into the curriculum.

#### *Phase 4 (Academic Year 2027-2028)*

In Phase 4, we will reactivate gap analysis and introduce new courses, if necessary. We will conduct a self-evaluation of the entire CDIO implementation process to identify areas for further refinement and ensure the long-term sustainability of CDIO principles within the Mechatronics and Robotics curriculum.

#### *Phase 5 (Academic Year 2028-2029)*

The final phase focuses on capstone-project based assessment. This phase assesses the

effectiveness of the implemented CDIO skills and makes adjustments as needed. (Cheah, S.M., Phua, S.T. and Claire H.T. Ng, The Chemical Engineering CDIO Experience After 5 Years of Implementation)

### ***Analysis of the Existing Mechatronics and Robotics Program***

Before embarking on the integration of CDIO principles, a thorough analysis of the existing mechatronics and robotics program is imperative. This step involves assessing the strengths and weaknesses of the current curriculum, pedagogical methods, and learning outcomes. Faculty members, industry experts, and students should collaborate in this evaluation process.

The analysis should consider the alignment of the program with industry needs, technological advancements, and the evolving landscape of mechatronics and robotics. It should also evaluate the extent to which the current program fosters essential skills such as teamwork, communication, and problem-solving—qualities that the CDIO program emphasizes. (Cheah, S.M. and Yang, K., CDIO Framework and Skillsfuture: Redesign of Chemical Engineering Curriculum After 10 Years of Implementing CDIO)

Feedback from alumni and industry stakeholders can provide valuable insights into the program's effectiveness in preparing graduates for real-world challenges. Identifying areas for improvement and understanding the unique characteristics of the existing program sets the stage for a targeted and meaningful integration of CDIO principles.

The Table 1 shows a comparison of curriculum of Mechatronics and Robotics major of ETUT and University of Dhaka. Our decision to acknowledge the high level of excellence in both curricula sets a positive tone from the outset. This demonstrates a respectful and objective approach to the comparison. The self-analysis we conducted on ETUT's curriculum showcases our proactive engagement with our own education. By reflecting on the program's strengths and areas for potential improvement, we demonstrate a commitment to continuous learning and a desire to optimize the educational experience. Comparing ETUT's curriculum with a well-regarded university like the University of Dhaka allows us to benchmark our program against established standards. This comparative analysis can reveal areas where ETUT excels and identify potential areas for further development.

Instead of focusing solely on shortcomings, we can frame the gap analysis as an opportunity for growth. By identifying areas where the University of Dhaka's curriculum might offer additional depth or different approaches, we can propose ways to enhance the learning experience at ETUT. This demonstrates a forward-thinking and improvement-oriented perspective. Our comparison has the potential to yield positive outcomes for both universities. Sharing best practices identified through the analysis could benefit both institutions. Additionally, our work could serve as a valuable resource for future curriculum development efforts at ETUT.

Table 1. Comparing of curriculum of Engineering and technology university of Turkmenistan (ETUT) and University of Dhaka

| ENGINEERING AND TECHNOLOGY<br>UNIVERSITY OF TURKMENISTAN                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                            | UNIVERSITY OF DHAKA                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                              |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fall semester                                                                                                                                                                                                                                                          | Spring semester                                                                                                                                                                                                                                                                                                            | Fall semester                                                                                                                                                                                                                                                                                                                       | Spring Semester                                                                                                                                                                                                                                                                                                                                              |
| <p>Mathematical analysis and differential equations<br/>Linear Algebra<br/>English for profession<br/>Mechanics<br/>Biology and bionics for engineers<br/>Japanese for profession<br/>Contemporary computer technologies<br/>SFIT</p>                                  | <p>Mathematical analysis and differential equations<br/>English for profession<br/>Engineering and computer graphics<br/>Chemistry for engineers<br/>Theoretical mechanics and strength of materials<br/>Biology and bionics for engineers<br/>Japanese for profession<br/>Contemporary computer technologies<br/>SFIT</p> | <p>Differential and Integral Calculus<br/>Fundamentals of Mechanical Engineering<br/>Fundamentals of Computing<br/>Physics<br/>Chemistry<br/>Physics Lab<br/>Chemistry Lab<br/>Engineering Drawing Lab<br/>Machine Shop and Workshop<br/>Practices Lab</p>                                                                          | <p>Fundamentals of Mechatronics Engineering<br/>Fundamentals of Electrical and Electronics Engineering<br/>Fundamentals of Programming<br/>Linear Algebra<br/>Accounting<br/>Functional English<br/>Fundamentals of Mechatronics Engineering Lab<br/>Fundamentals of Programming Lab</p>                                                                     |
| <p>Theory of functions of a complex variable<br/>English for profession<br/>Control system techniques<br/>Electricity and magnetism<br/>Digital electronics<br/>Computer programming<br/>Japanese for profession<br/>Ecology and environmental protection<br/>SFIT</p> | <p>Fundamentals of mechatronics<br/>English for profession<br/>Control system techniques<br/>Electrotechnics and electronics<br/>Digital electronics<br/>Computer programming<br/>Japanese for profession<br/>Life safety<br/>SFIT<br/>Professional practice</p>                                                           | <p>Instrumentation and Measurement<br/>Digital Logic Circuit and Microprocessor<br/>Engineering Mechanics<br/>Multivariate and Vector Calculus<br/>Managerial and Engineering Economics<br/>Society and Technology<br/>Instrumentation and Measurement Lab<br/>Digital Logic Circuit and Microprocessor Lab</p>                     | <p>Introduction to Robotics<br/>Microcontroller and Programmable Logic Controller<br/>Object Oriented Programming<br/>Electrical Machines<br/>Differential Equations and Coordinate Geometry<br/>Statistics for Engineers<br/>Introduction to Robotics Lab<br/>Microcontroller and Programmable Logic Controller Lab<br/>Object Oriented Programming Lab</p> |
| <p>Electrotechnics and electronics<br/>Measurement techniques<br/>Material science and photonics<br/>Computer programming<br/>Theoretical Innovatics<br/>Communication techniques<br/>SFIT</p>                                                                         | <p>Numerical methods<br/>Robotics<br/>Artificial Intelligence<br/>Applied programming<br/>Theory of economics<br/>Energy safety and "green engineering"<br/>SFIT<br/>Metrology, standardization and certification<br/>Professional practice</p>                                                                            | <p>Artificial Intelligence<br/>Advanced Mechatronics Engineering<br/>Mechanics of Solids and Fluids<br/>Mathematical Analysis for Engineers<br/>Industrial Management<br/>Artificial Intelligence Lab<br/>Advanced Mechatronics Engineering Lab<br/>Mechanics of Solids and Fluids Lab</p>                                          | <p>Intelligent Systems and Robotics<br/>Manufacturing Process with CNC Programming<br/>Power Electronics and Drives<br/>Control Systems Design<br/>Bangladesh Studies<br/>Intelligent Systems and Robotics Lab<br/>Manufacturing Process with CNC Programming Lab<br/>Power Electronics and Drives Lab</p>                                                   |
| <p>Data mining<br/>Image recognition<br/>Digital signal processing<br/>Digital economy<br/>Fundamentals of Biotechnology<br/>SFIT<br/>Work on graduation thesis</p>                                                                                                    | <p>Smart material's technology<br/>Basics of nanotechnology<br/>Basics of chemical technology<br/>SFIT<br/>Work on graduation thesis</p>                                                                                                                                                                                   | <p>Advanced Robotics<br/>Digital Image Processing and Robot Vision<br/>Digital Signal Processing<br/>Mechanical Power Transmission Systems<br/>Advanced Robotics Lab<br/>Digital Image Processing and Robot Vision Lab<br/>Digital Signal Processing Lab<br/>Research Methodology, Technical and Scientific Writing Lab Project</p> | <p>Human Robot Interaction<br/>Optional Course I (From Group A)<br/>Optional Course II (From Group B)<br/>Human Robot Interaction Lab<br/>Optional Course I Lab (From Group A) Project</p>                                                                                                                                                                   |

## Integration of CDIO Principles and Components into the Educational Program

Figure 2 focuses on mapping of curriculum of Mechatronics and Robotics major. We've created a table that maps curriculum subjects to CDIO skills, taking a strategic approach to ensure students develop the necessary competencies. This visual representation allows for easy identification of subjects that naturally integrate CDIO principles, represented by the red circles. Our analysis has identified subjects which present ideal opportunities for incorporating CDIO skills. This demonstrates a keen understanding of both the CDIO framework and the Mechatronics and Robotics curriculum. We've highlighted the interrelationships between subjects within the curriculum, a valuable contribution. (Cheah, S.M., Integrating CDIO Skills in a Core Chemical Engineering Module: A Case Study) Understanding how subjects connect is crucial for holistic learning. By showcasing these connections, we emphasize the program's ability to provide students with a comprehensive understanding of Mechatronics and Robotics. This mapping exercise serves as a valuable tool for faculty in developing and refining pedagogical approaches to effectively integrate CDIO principles into coursework. By identifying areas of strong CDIO integration, we can build upon existing strengths, while also utilizing the gaps identified to introduce further CDIO elements in other subjects. A curriculum that intentionally integrates CDIO skills equips students with a valuable skillset. They will graduate with the ability to conceive, design, implement, and operate mechatronic and robotic systems – a crucial skillset in today's engineering landscape. Our proactive approach to curriculum mapping for CDIO integration highlights a commitment to providing students with the best possible education in Mechatronics and Robotics. This work has the potential to serve as a valuable resource for faculty and improve the overall effectiveness of the program.

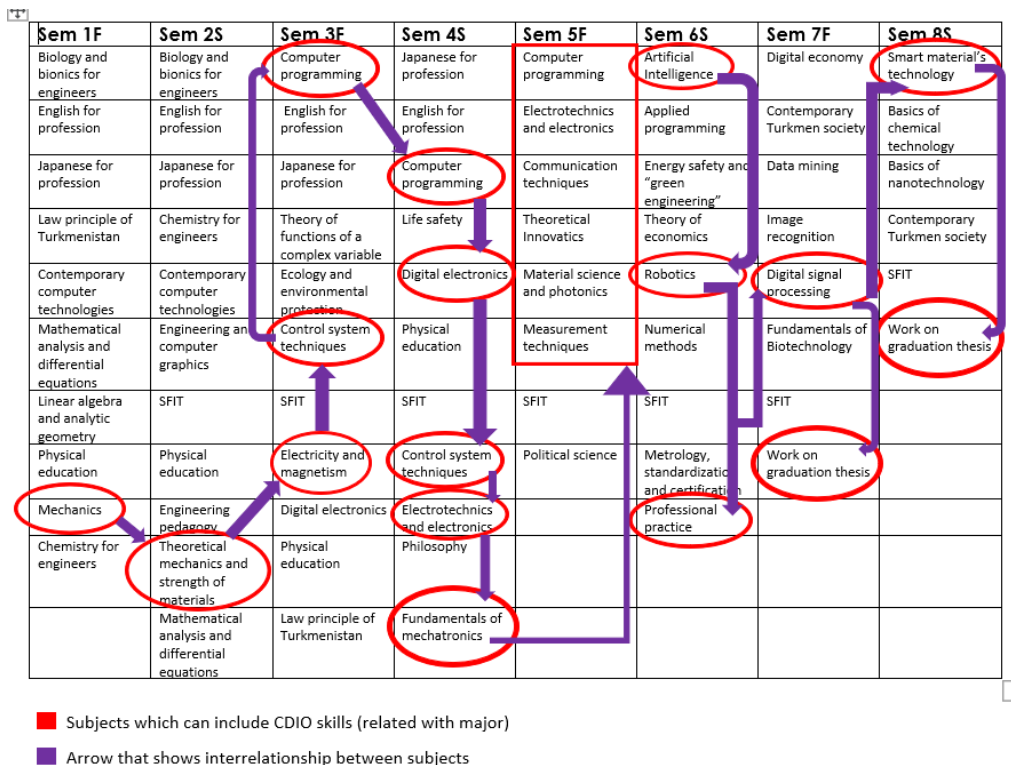


Figure 2. Mapping of curriculum of Mechatronics and Robotics major

The integration of CDIO principles into the mechatronics and robotics program is a strategic process that involves aligning the existing curriculum with the core tenets of the CDIO framework. This integration goes beyond a superficial overlay; it necessitates a fundamental shift in pedagogy and educational philosophy. (Crawley, E.F., Malmqvist, J., Ostlund, S. and Brodeur, D.R., Rethinking Engineering Education)

Continuous feedback loops and regular reflection sessions should be implemented to allow students to learn from both successes and failures. Additionally, faculty development programs may be necessary to equip instructors with the skills needed to effectively implement CDIO principles.

### **Development of Specialized Educational Modules and Courses**

To further enhance the integration of CDIO skills, the development of specialized educational modules and courses becomes essential. These modules can address specific aspects of the CDIO framework, providing in-depth exploration and hands-on experiences.

Consider developing modules that focus on interdisciplinary collaboration, effective communication, and project management—key components of CDIO. These modules can be designed as standalone courses or integrated into existing ones, ensuring a seamless progression through the educational journey. (Bruun, E. and Kjærgaard, C., A Model for The Development of a CDIO Based Curriculum in Electrical Engineering)

Collaboration with industry partners for these specialized modules can offer students exposure to real-world challenges and foster connections between academia and industry. Industry-relevant projects, guest lectures, and internships can complement the theoretical aspects of the program, enriching students' understanding and application of CDIO skills.

Table 3.a. Relation between anticipated learning outcomes of Mechatronics and Robotics major and skills of CDIO Syllabus

| Learning outcomes                                | Skills                                              |
|--------------------------------------------------|-----------------------------------------------------|
| Elementary scientific learning outcome           | 1.1. Core Engineering Fundamental Knowledge         |
|                                                  | 1.2. Advanced Engineering Fundamental Knowledge     |
| Enterpreunership/sustainability learning outcome | 4.2. Enterprise and business context                |
|                                                  | 4.8. Enterpreunership                               |
| Communication learning outcome                   | 3.2. Communications                                 |
|                                                  | 3.3. Communications in foreign languages            |
| Research learning outcome                        | 4.3. Conceiving, systems engineering and management |
|                                                  | 4.4. Designing                                      |
|                                                  | 4.5. Implementing                                   |
|                                                  | 4.6. Operating                                      |
| Engineering learning outcome                     | 2.1. Analytical reasoning and problem solving       |
|                                                  | 2.3. System thinking                                |
| Sustainable development learning outcome         | 2.5. Ethics, equity and other responsibilities      |

In conclusion, the successful integration of CDIO skills into the mechatronics and robotics educational program requires a thoughtful and strategic approach. By conducting a thorough analysis, aligning with CDIO principles, and developing specialized modules, educational institutions can create a transformative learning experience that produces graduates equipped with the multifaceted skills demanded by the dynamic field of mechatronics and robotics.

Table 3 represents the analysis of curriculum of mechatronics and robotics major. It shows the subjects that can include the defined learning outcomes. The table we've created for our CDIO paper goes beyond a simple listing of subjects. By assigning a distinct color to each of the six learning outcomes and then applying those colors to relevant subjects, we've developed a visually compelling and informative tool. This color-coding system allows for quick identification of which subjects address specific learning outcomes.

Table 3.b. Analysis of learning outcomes of the courses

|   |                                     |                                                  |                                   |                                        |                                                 |                           |                                              |                         |                                                    |
|---|-------------------------------------|--------------------------------------------------|-----------------------------------|----------------------------------------|-------------------------------------------------|---------------------------|----------------------------------------------|-------------------------|----------------------------------------------------|
| 1 | Contemporary computer technologies  | Mathematical analysis and differential equations | Mechanics                         | Chemistry for engineering              | Linear algebra and analytic geometry            | English for profession    | Japanese for profession                      | Other modules           | Scientific fundamentals of innovative technologies |
| 2 | Biology and bionics for engineering | Contemporary computer technologies               | Engineering and computer graphics | Mathematical analysis and differential | Theoretical mechanics and strength of materials | Chemistry for engineering | English for profession                       | Japanese for profession | Scientific fundamentals of innovative technologies |
| 3 | Computer programming                | Theory of a complex variable                     | Digital electronics               | Ecology and environmental protection   | Electricity and magnetism                       | Control system techniques | English for profession                       | Japanese for profession | Scientific fundamentals of innovative technologies |
| 4 | Computer programming                | Digital electronics                              | Fundamentals of mechatronics      | Control system techniques              | Electrotechnics and electronics                 | Life safety               | English for profession                       | Japanese for profession | Scientific fundamentals of innovative technologies |
| 5 | Theoretical Innovatics              | Computer programming                             | Material science and photonics    | Communication techniques               | Electrotechnics and electronics                 | Measurement techniques    |                                              |                         | Scientific fundamentals of innovative technologies |
| 6 | Theory of economics                 | Energy safety and 'green engineering'            | Applied programming               | Robotics                               | Artificial intelligence                         | Numerical methods         | Metrology, standardization and certification |                         | Scientific fundamentals of innovative technologies |
| 7 | Digital economy                     | Image recognition                                | Digital signal processing         | Fundamentals of biotechnology          | Data mining                                     |                           |                                              |                         | Scientific fundamentals of innovative technologies |
| 8 | Smart material's technology         | Basics of chemical technology                    | Basics of nanotechnology          | Work on graduation thesis              |                                                 |                           |                                              |                         | Scientific fundamentals of innovative technologies |

Our analysis doesn't stop at learning outcomes. By further associating each learning outcome with specific CDIO skills, we demonstrate a clear understanding of how our curriculum integrates with the CDIO framework. This color-coded representation offers several advantages. It simplifies the complex task of curriculum analysis by providing a clear visual representation of how subjects contribute to achieving specific learning goals. Faculty can readily see which subjects align with particular learning outcomes and CDIO skills.

This analysis can be a valuable tool for our future curriculum development efforts. By identifying areas where certain learning outcomes or CDIO skills may not be well-represented by existing subjects, opportunities for curriculum refinement can be identified. Additionally, the

color-coding system can be used when developing new courses or learning activities to ensure alignment with established learning outcomes and CDIO principles. (Sale, D. and Cheah, S.M., Writing Clear Customized Learning Outcomes with Key Underpinning Knowledge)

## **CONCLUSION: TRANSFORMING MECHATRONICS AND ROBOTICS EDUCATION WITH CDIO INTEGRATION**

The integration of CDIO skills into mechatronics and robotics education represents a transformative journey, enriching the learning experience and producing graduates ready to tackle the complexities of the modern engineering landscape. As we reflect on the key facets explored in this article, it becomes evident that CDIO's principles bring a paradigm shift to educational practices, ensuring a comprehensive and relevant preparation for future engineers.

The advantages of implementing CDIO skills are multifaceted and impactful. Education quality in mechatronics and robotics is enhanced, producing graduates who not only possess technical expertise but also critical skills for success. Teamwork and communication skills are refined through interdisciplinary collaboration, reflecting the collaborative nature of the industry. Strengthened connections with industry stakeholders ensure that educational programs remain relevant and meet the evolving needs of the labor market. (Malmqvist, J., Hugo, R. and Kjellberg, M., A Survey of CDIO Implementation Globally – Effects on Educational Quality)

In conclusion, the integration of CDIO skills into mechatronics and robotics education emerges as a catalyst for innovation and excellence. By embracing the principles of the CDIO program, educational institutions empower students to not only navigate the intricacies of technology but also to thrive in collaborative, dynamic environments. This transformative approach ensures that graduates are not merely recipients of knowledge but architects of solutions, poised to shape the future of mechatronics and robotics. As the educational landscape evolves, the integration of CDIO skills stands as a beacon, guiding the next generation of engineers towards success and leadership in the ever-evolving fields of mechatronics and robotics.

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# REDUCING ABSENTEEISM IN THE CLASSROOM: TWO CASE EXAMPLES

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## ABSTRACT

One of the most challenging situations in nowadays education at all levels is attracting and retaining the attention and motivation of the students. This situation has been deeply aggravated by the COVID situation, where the possibility of on-line lessons has led to new typologies of remote approaches. In this work, developed at the Barcelona School of Telecommunications Engineering (ETSETB) of the Universitat Politècnica de Catalunya (UPC), we describe the use of different methodologies to increase the student's attendance to the classes. We evaluate two different case scenarios. Case 1 is the change of teaching strategy in the Sustainability & Ethics (S&E) seminars in project-based courses of bachelor's degrees. And Case 2, is a core subject master's degree in Telecommunications Engineering. Case 1 scenario consists of introducing S&E competences in a bachelor-level Product Development Project course where students work in teams. These competences are taught through master-class-style led seminars. The seminars show a high absenteeism level, as most of the teams decided to send just one representative of the team to attend to them. The solution proposed to Case 1 scenario consists on reducing the master-class exposition time and substituting it by a hands-on workshop on how to develop the S&E report on the specific project topic of each team. This has increased the attendance to class, from 20% to 85% approximately in this track. The motivation has been also noticeably increased. Case 2 scenario analyses the subject Electronics Instrumentation and Optoelectronics (EIO). The subject has 80% contents of theoretical knowledge. The attendance to the theory lessons during the last few years was very low, especially after the COVID situation, roughly estimated to be a 35%, and the evaluation results showed that the final exam scores had decreased dramatically. With this starting point, the theory lessons have been changed by reducing the master-class part, including short individual open-book exams during the lessons and a final challenge-based (CB) activity related to the theory contents. The class attendance has increased from 35% to 95% and the motivation of the students attending to the class has been noticeably increased as well.

## KEYWORDS

Absenteeism, Attendance, Motivation, Engagement, CDIO Standards 3, 4, 5, 7, 8.

## INTRODUCTION

It is well known that absenteeism has negative impact on academic performance in higher education. It is also known that students with low performance are worse affected by absenteeism than the ones with high performance (Pani, P.K., 2016). It is a behavior that contradicts the basic premises of the EHEA regarding the students' role and drives to an inefficiency of the use of public resources. According to Méndez-Suárez (2021), absenteeism effect on the academic performance of university students decreases as students progress on their degree. It has the greatest impact on academic performance of first and second-year undergraduate students, a moderate effect on the one of third-year and fourth-year students, and a negligible effect on academic achievement of fifth-year students.

Several authors have performed multifactorial studies trying to identify the most important reasons that influence absenteeism in university classrooms from the students' perspective and all of them agree on the complexity of the topic and on that there is no a single reason for it nor a single way of facing it. Triadó-Ivern (2020) identifies five dimensions or reasons for absenteeism: students' own planning, teaching methodology, learning methodology, course characteristics, and availability of external sources. They also state that students' reasons that affect absenteeism differ with regard to their year and degree of study: in the first year, students mainly attribute absenteeism to external sources such as non-obligatory attendance. The second-year students are more focused on teaching methodology and on their own planning and, in the latter years, students put more accent on their learning methodologies.

In another study (Menendez Alvarez-Hevia, D., 2021) found that attendance is a situated decision that can be articulated in relation to two sets of factors. The first set refers to university imperatives, and which relate to discourses of performativity and accountability. The second set relates to the complexities of students' lives, and there is a tradeoff among them. S. Bakrania (2018) also describes this need to balance among opposing factors, such as study, family life, and financial commitments. The authors also identify the availability of recorded lectures as a determining factor for absenteeism.

López-Bonilla (2015) identifies seven determining factors of absenteeism: efficiency, teaching style, academic interest, teaching contents and format, classmates' influence and fears, imponderables and convenience, being 'Teaching Style' the factor which obtained the highest average score. In another paper R.J. Longhurst (1999) studies up to fifteen different types of reasons for student absenteeism. In partial contradiction with the previous authors, factors related to courses and teachers were found to be the least significant and the students' general degree of commitment to education was found to be the most important factor related to levels of absenteeism.

As expected, COVID-19 had a strong influence on both online absenteeism and post-COVID face-to-face absenteeism as stated by N. Jaftha (2022) in a literature review on the topic. The authors also state the complex and multifactorial nature of the phenomenon and that addressing absenteeism requires a combination of strategies and involves various actions and stakeholders. They conclude that evidence shows that a strong support system that shows interest in individual students' life and behavior can have a significant effect on students' attendance.

Socio-cultural factors can also play a role to determine which factors are more significant. In a study performed in India among Engineering students, I.S.P. James (2022) found that Distractions and Students' Health Conditions were more relevant than Teachers' Attitude and other factors, as regulatory conditions about attendance were stricter than in other countries.

About finding possible solutions, there is consensus in the complexity of this task. There is not a single way of facing the problem but all papers mention the need of increasing the motivation and engagement of students although not all of them put these factors at the forefront. The CDIO framework should be a good scenario to promote them and therefore, to reduce absenteeism. J. Early (2010) describes how an introductory module, Introduction to Aerospace Engineering, designed through the CDIO paradigm and using an active/interactive approach, improved the attendance up to virtually 100%, overcoming the absenteeism and lack of motivation which was endemic in Level 1 engineering classes. The students reported enjoying the class, and linked this to their attendance. Dewulf (2008) reported that team-dynamics in project-based courses according to the CDIO design-implement model (Standard 5) helps to reduce absenteeism. McCartan (2010) also verified that including active teaching methods improved results and reduced absenteeism in 1st year mathematics courses in engineering bachelor and Rodríguez-Rivero (2020) pointed out the importance of finding the balance between stress and satisfaction in CDIO experiences. They highlighted the importance of feeling valued and cared for by the ecosystem integrated by supervisors and colleagues to reach their satisfaction and about the value of doing exciting projects in a cooperative environment.

At the Barcelona School of Telecommunications Engineering (ETSETB) of the UPC, we are applying different methodologies to increase the student's attendance to the classes. In this work we evaluate two different case scenarios. The first one (Case 1) is the change of teaching strategy in the seminars of Sustainability & Ethics (S&E) in the project-based courses, which were already designed according to the CDIO standards. The other scenario (Case 2), is the change of methodology in a core subject with high theoretical content in the master's degree in Telecommunications Engineering, which had a classical lecture-problems-exam structure.

## **PROBLEM DEFINITION**

In order to better analyze the implementation of different CDIO tools, it was decided to address two different subjects that are, in nature, very different. They are located in different degrees, at different educational levels and with very different technical and duration contents. This will define two scenarios, that will cover more contents and context areas. In both cases, a historical comparison of the subject or seminar was conducted, but there was no parallel implementation with different groups and methodologies to facilitate the comparison. In this section, the initial situation of the two case scenarios is shown.

### ***Case 1 scenario: Bachelor's level seminar into a project-based course.***

Case 1 scenario consists of introducing S&E competences in a bachelor-level Product Development Project (PDP) course. The PDP course addresses different technical projects that have to be solved by teams of 8 to 12 students each. The subject has 12 ECTS spread into 6 hours per week of hands-on design-build activities and 2 hours per week of seminars, plus autonomous work. Contents and methods about innovation and entrepreneurship, project management, intellectual property, critical and systems thinking and S&E tracks are taught in

the seminar sessions. The subject is located on the seventh semester (fourth year) of the four-year bachelor's degree in Electronic Telecommunication Engineering.

In this case scenario, only the S&E seminar is analyzed, consisting in two sessions of expository class of two-hours each. The contents are evaluated by developing a report and a presentation of the S&E analysis of the technical PDP project of each team. The first session was about the sustainability aspects and the second one about the ethical aspects. The sessions were mostly expository (master-led cl) but using frequent interactions through tools like Kahoot. These Sustainability Analysis seminar was introduced 6 years ago, and the Ethical Analysis seminar 2 years ago.

Attendance to the design-build lab sessions is virtually 100%. The teams' self-management does not allow absences that could delay the project milestones except in few and justified cases. Students are, however, a lot more tolerant with the attendance to the seminars as they do not perceive their usefulness for the project results. Most of the teams decide to send just one or two representatives to attend to the seminars in order to be able to fulfill the corresponding part in the Final Report. As a result, the attendance to the seminars was typically around 20% (See Table 1). Given the growing relevance that our institution is giving to the Sustainability and Ethics topic, two years ago it was decided to announce that the attendance to these sessions was mandatory, and attendance lists were distributed in each session. This led to a variable increase in the assistance that ranged from 51% up to 80%, but this did not mean that all students were attentive in the session, and the attendance to the other seminars was as low as usual. This last year, in order to measure the real interest of the students on the new hands-on methodology, the attendance was not mandatory, and the students came willingly and more committed to the task, increasing the attendance to an 85%.

Table 1. Case 1 scenario, showing the historical bachelor level seminar attendance.

| Year-semester    | Attendance (%) |
|------------------|----------------|
| < 21-22          | 20             |
| 21-22 (1)        | 29             |
| 21-22 (2)        | 21             |
| 22-23 (1)        | 51             |
| 22-23 (2)        | 80             |
| <b>23-24 (1)</b> | <b>85</b>      |

The numbers in Table 1, as well as students' questioning and final results evaluated by different professors, draw the following conclusions:

- The average attendance is low (20% to 29%) on the first years.
- Asking the students, most of them refer that the expository description of the S&E contents in these seminars do not seem to add significant value compared to reading the material by themselves.
- Usually, only one person per group will attend in person, not sharing the information with the rest, that do not find necessary to learn the seminar part.
- The students do not have sufficient feedback till it is too late, so the learning process is not fully achieved.
- The analysis of the final presentations and reports shows that the students do not fully understand and therefore they do not really value the content of the work to be done.

### **Case 2 scenario: Master's level core subject.**

Case 2 scenario analyses a core subject of the two-year master's degree in Telecommunications Engineering: Electronics Instrumentation and Optoelectronics (EIO). This is a 5 ECTS subject with 3 hours per week. The subject has 80% contents of theoretical knowledge. The master has particularities that might have influenced the attendance pattern:

- The 120 ECTS, two-years Master is mandatory for the Telecommunication Engineers which would like to have a national professional accreditation. This leads to a situation in which the content of the master has to be highly multidisciplinary. The contents of the subjects are specified by the Spanish Ministry of Education. Since 2019, the students that do not need or do not want this accreditation can choose more specialized and shorter masters (60 ECTS) This fact has modified the number and the origin of the students that enroll for the two-year master.
- The incoming students have different origins, thus having different background and motivation.

The subject has been taught since year 2013. The methodological approach all these years has been mainly expository master-led class, usually in combination with paused method (Fa'eza Adnan, 2019). As for the evaluation, the final score has always a 20% of practical work in the laboratory, developed in groups of two people. The other 80%, commonly taught in the expository-led-class approach, has faced different evaluation methods. In all of them, a Final Exam has kept a weight of 60% of the total subject score, whereas the remaining 20% has been assigned to the following assessment formats:

- A midterm exam developed individually in class.
- Short Quizzes developed individually in class.
- Exercises developed individually as homework.
- Individual research work developed individually as homework.

The midterm exams, final exams and quizzes have been also held in different formats: multiple choice and-or problems and with open-book or not open-book formats. No significant differences due to the format of the evaluation have been found. However, when the midterm exam or the quizzes were skipped, the final exam score used to be lower. Table 2 shows the historical information about the subject, including the methodological approaches, the assessment methods, the attendance and the average of the final score (from 0 to 10). The last file of Table 2 shows the results of the new methodological approach. In all cases, the attendance has not been thoroughly monitored, but it is a rough estimation.

Table2: Master's core subject historical information.

| Year-semester | Methodological approach | Assessment Method           | # Students | Attendance (%) | Average Final subject score |
|---------------|-------------------------|-----------------------------|------------|----------------|-----------------------------|
| 13-14 (1)     | Expository-Paused       | Exercises and Final Exam    | 6          | 90             | 5.7                         |
| 14-15 (1)     | Expository - Paused     | MidTerm Exam and Final exam | 24         | 70             | 7.9                         |
| 15-16 (1)     | Expository - Paused     | Quizzes and Final exam      | 29         | 70             | 7.5                         |

|                  |                                           |                                          |           |           |            |
|------------------|-------------------------------------------|------------------------------------------|-----------|-----------|------------|
| 16-17 (1)        | Expository-<br>Paused                     | MidTerm Exam<br>and Final exam           | 36        | 60        | 7.1        |
| 16-17 (2)        | Expository-<br>Paused                     | MidTerm Exam<br>and Final exam           | 33        | 60        | 6.7        |
| 17-18 (1)        | Expository-<br>Paused                     | MidTerm Exam<br>and Final exam           | 38        | 50        | 7          |
| 17-18 (2)        | Expository-<br>Paused                     | MidTerm Exam<br>and Final exam           | 36        | 50        | 6.9        |
| 18-19 (1)        | Expository-<br>Paused                     | Exercises and<br>Final Exam              | 31        | 50        | 7.4        |
| 18-19 (2)        | Expository-<br>Paused                     | Exercises and<br>Final Exam              | 41        | 50        | 7          |
| 19-20 (1)        | Expository-<br>Paused                     | Exercises and<br>Final Exam              | 26        | 50        | 7.0        |
| 19-20 (2)        | Expository-<br>sync. and<br>async. videos | Exercises and<br>Final Exam              | 18        | COVID     | 6.7        |
| 20-21 (1)        | Expository                                | Exercises and<br>Final Exam              | 18        | 40        | 6.5        |
| 20-21 (2)        | Expository                                | Exercises and<br>Final Exam              | 19        | 40        | 5.9        |
| 21-22 (1)        | Expository                                | Exercises and<br>Final Exam              | 18        | 35        | 6.7        |
| 21-22 (2)        | Expository                                | Research work<br>and Final Exam          | 21        | 35        | 5.9        |
| 22-23 (1)        | Expository                                | Research work<br>and Final Exam          | 30        | 35        | 6          |
| 22-23 (2)        | Expository                                | Research work<br>and Final Exam          | 19        | 35        | 5.3        |
| <b>23-24 (1)</b> | <b>Expository-<br/>CB</b>                 | <b>Quizzes and CB<br/>and Final Exam</b> | <b>31</b> | <b>95</b> | <b>8.4</b> |

## THE PROPOSED METHODOLOGICAL APPROACH

In this section, the proposed solution for the problems and limitations identified in the previous section is described. In both cases, the methodological approach is rooted in the need to engage students in their learning process to decrease absenteeism. Building on this foundation, two distinct implementations will be utilized, each tailored to the specific contents and context of the two defined scenarios. In both cases, the students were told that a different methodology would be used with the aim of having a better learning experience, explaining the limitations of the previous one and justifying the design of the new one.

### **Case 1 scenario: Bachelor's level seminar into a project-based course.**

The analysis of the historical situation of the S&E seminar in the bachelor's level subject, led to the main conclusions described in the previous section. Summarizing, the students' attendance was very low and only a small part of each group developed the necessary work demanded on the S&E presentation and report. This last semester 23-24 (1), the methodological approach has been focused in substituting the two expository sessions by:

- In the first S&E two hours seminar session:
  - One hour of expository class, including active approximations to the audiences using Mentimeter.
  - One hour of hands-on work by teams, understanding the S&E report with the specific case of each team's project.
- Second S&E two hours session:
  - Developing the final S&E report with the specific case of each team's project.
  - Developing the final S&E presentation part, following an elevator pitch presentation orientation.
- Evaluation remains the same: S&E report and presentation.

This approach has led to the following conclusions:

- The absenteeism has been reduced to approximately 15% (85% attendance).
- Many of the students of the group have actively participated in the project and thus in the learning process.
- There is sufficient and timely feedback to the students about the report and presentation contents. Again, they participate and are more active in the learning process.
- The motivation of the students in the hands-on learning sessions was unexpectedly high.

### **Case 2 scenario: Master's level core subject.**

Trying to diminish the subject drawbacks, this last year (2023-2024 (1), Fall term), a new methodological approach in addition to a new evaluation process have been implemented. Mainly, the theory lessons have been changed by reducing the expository part, including short individual exams during the lesson, and a challenge-based (CB) activity. Alternatively, the students may choose to score the 80 % on the final exam, if they decide not to attend to the class. The description of the novel path learning methods and evaluation processes introduced in the subject are listed below:

- In terms of the learning methodology:
  - The theoretical classes will be divided into eight master-class sessions and five CB work sessions.
  - The reduction of the expository sessions has not significantly reduced the contents. Some parts have been adapted for students to do the work at home.
  - The master-class sessions will include up to two short individual exams (quizzes).
  - The CB project is based on finding a technical solution, using the technologies described in the theoretical lessons, to one of the targets of a Sustainable Development Goal (SDG) goals. The SGD goal has been chosen by the professor, in this case is SGD 6: Clean water and sanitation.
  - The CB project is developed in groups of up to four people.
  - The CB project follows partially the design thinking methodologies.
  - The CB sessions have been daily guided and monitored by the teacher, helping to reach different milestones and evaluating the project process achievements.



- In terms of the evaluation methods of the theoretical part of the subject, which weights a maximum of 80%, the students can choose between two options:
  - Performing the individual short exams during the theory lessons (30%) and developing the CB project (20%) with a 30% of a final exam.
  - The whole theoretical score (80%) can be assessed with a final exam. So, in this case, they can decide not to attend to the class.

Examples of the CB projects developed by the students are listed below:

- Designing an Automated Water Sensing System for Remote Monitoring of Water Parameters in Venezuela.
- RAMAN spectroscopy and indirect drinking water treatment for groundwater sources.
- Microalgae detection using spectrophotometry.
- Measurement of salinity at Llobregat river by using Laser Induced Breakdown Spectroscopy (LIBS).
- Fluorescence Spectroscopy to detect dissolved organic matter (DOM).
- Hyperspectral imaging solution for microplastic detection in residual waters.
- Microplastics annihilation through laser targeting.
- Real-Time monitoring of fluorescent organic dyes at river pollution sources.

Some of the results found with this methodology were somehow not completely as expected:

- Attendance increased even in the expository classes (70%), reaching a 100% attendance in most of the CB project sessions. On average, the attendance was 95%.
- All the students decided to choose the continuous evaluation alternative including the short exams and the CB project work.
- The motivation of the students in the CB project sessions was unexpectedly high.
- The participation in the theoretical classes was, however, still low.
- First implementation of this method shows an increase in the average subject score, and all the students passed the subject.

## DISCUSSION

In this work we have shown a methodological analysis of the absenteeism in two different subjects. One of them consists of a two-session Sustainability and Ethics seminar in a PDP subject at a bachelor level. The other is a core subject at a master's level. The bachelor's seminar had a low historical average attendance, of 20%. The master's core subject has experienced a monotonal decreasing attendance starting in an 70% and reaching a constant value of 35%. Although the reasons for the absenteeism in both cases may differ, they have in common the lack of motivation for the methodological learning approach: the students seem to believe that they can manage to acquire the knowledge without attending to the class or, even worse, that they do not need that knowledge to perform good results. This has been proven to be a mistake, as most of them get lower scores when not attending to the class sessions. The evaluation methods may also have an impact, but they are not the only driving force, as demonstrated in the Table 2 data, where different evaluation processes have been tested without finding a clear correlation with the attendance levels nor with a variation in the final average score. In the bachelor's level seminar, the approach of substituting the expository explanation by a hands-on work on the specific contents, has clearly increased not only the attendance to the lessons (from 20% to 85%) but also the interest and necessary feedback from the professors to the students in the learning process. The method will be transferred gradually to the other seminars, which are taught by other lecturers, gradually. In the master's

core subject, the inclusion of a CB project directly related to the theory contents has significantly increased the attendance to class from 35% up to 95%. The modification on the evaluation process, concentrating the short exams at the beginning has also increased the concentration of the students on the theory lessons, although there is still a long path to overcome the initial demotivation for the subject contents, and the quite steep learning curve of these theoretical contents. This may highlight one of the most challenging limitations of these methods: overcoming the well-established unidirectional teaching approaches, where the student is accustomed to being a passive receiver of the most difficult theoretical knowledge. Future work will be focused on introducing some modifications of the theoretical part so as to guide the learning process with introducing small milestones, that will be continuously evaluated. In attempting to extend these methodologies to other subjects, this work has demonstrated the importance of involving students in their learning process to decrease absenteeism levels. Although it is necessary to adjust the methodology to the context and the contents of each particular subject, there may be some generalizations in the approach: (i) Students must feel the necessity of attending class, not only due to assessment pressure. (ii) Continuous and guided work stresses the importance of attending to class; and (iii) Challenge-based approaches, such as real-world problem contexts, regardless of the subject's content, help increase the involvement and motivation of students in their learning process.

## **CONCLUSIONS**

This work has faced the problem of absenteeism in two different case scenarios, one a two-session bachelor's level seminar in a Product Development Project subject, and the other a master core subject. Both of them have in common that they start with very low attendance levels (20% and 35%, respectively). Introducing experiential activities related with the project topic in the first case and a SDG-based challenge in the second one, with guided feedback from the supervisors has unexpectedly increased the attendance levels to 85% and 95%, approximately. Specifically in the master core subject, the introduction of a Challenge Based project directly related to the contents of the subject has been very well received by the students. And although there is still work to be done to get them to keep up with the more difficult theoretical parts of the subject, the students are clearly more engaged in the learning process, especially in the Challenge Based project, in which some of them are particularly committed.

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# DESIGN THINKING AND PROJECT-BASED LEARNING IMPLEMENTATION THROUGH COMPETENCY-BASED MODEL AND CRITERION-REFERENCED ASSESSMENT

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## **ABSTRACT**

Engineering education is a challenging subject due to the particularity of skills acquisition issues in nowadays context. Students need to acquire diverse talents that are essential for career prospects beyond technical skills. Project-based learning (PBL) is a submerging pedagogical approach that applies active training by targeting the different learning outcomes needed for engineers through authentic, real-world educational scenarios. Even though it offers many advantages helping students to enhance their soft skills as well as the hard ones, it also faces some challenges such as assessment mechanisms, learners engagement and motivation, teamwork and conflict management, and harmonious integration in the curriculum. In line with our commitment to excellence in engineering education, we have integrated the PBL method, harmonized it with CDIO (Conceive, Design, Implement, and Operate) standards, and combined it with a design thinking (DT) methodology. This initiative was experimented with the second-year common core computer science engineering students at ESPRIT School of Engineering. The evaluation of students in this project is based on a detailed criterion-referenced assessment (CRA) derived from the learning outcomes of the module. This competency-based evaluation includes various metrics to measure skills acquisition based on the contribution of each student, his commitment, and collaboration with the other team members, and his creative engineering skills. In this paper, we will show how effective this DT-PBL experience was thanks to the use of CRA providing detailed insight into the performance of each learner. As a consequence, we were able to collect valuable feedback to highlight the areas of improvement. Besides, this evaluation method boosted transparency by clarifying the expectations and the evaluation criteria to the learner. Based on the experiments, we will show that this valuable and meaningful competency-based educational model ensured better individual achievement in the learning process.

## **KEYWORDS**

Project-based learning, Design thinking, DT-PBL, criterion-referenced assessment, Engineering Education, Standards: 2, 5, 7, 8, 11

## INTRODUCTION

Various educational experts have suggested numerous adaptations of the CDIO standards (Edström & Kolmos, 2014), to improve the quality of training provided to engineering students. These adaptations aim to reinforce the relevance and applicability of the acquired skills, through exposure to educational experiences that reflect the challenges and demands of the professional world. This paper presents a module inspired by the CDIO (Conceive, Design, Implement, and Operate) educational approach. It adopts an active learning method, Project Based Learning (PBL) (Edström & Kolmos, 2014), which encourages training through the realization of a project in line with precise specifications.

This method helps engineering skills acquisition such as problem-solving, professional ethics, and critical thinking. So this contribution implements a DT-PBL (Design Thinking - Project Based Learning) pedagogical strategy. Through discussions and brainstorming among team members, we motivate students' design thinking (DT), innovation, and creativity to generate possible solutions based on prior knowledge and collected information. Within the scope of this project, the students are challenged to create ERM (Enterprise Resource Management) applications relying on a chosen topic. The technical backdrop involves the use of the C++ programming language within the QT framework, Oracle DBMS, Git, and Github. Besides, the developed solutions generally integrate an electronic part using sensors and Arduino uno microcontrollers to get started on embedded programming. Furthermore, we opted for the GitHub classroom workflow as a project and version management tool to enable progress tracking through project boards, effective collaboration, and proactive problem-solving which contributed to ensuring smoother development processes and high-quality delivered output.

The organization of the paper unfolds as follows: In Section 2, an exhaustive review of relevant literature about the PBL approach is presented. Section 3 delineates the methodology adopted to implement DT-PBL in our context, offering intricate details about the assessment method while comparing an old approach with a new one. The details about CDIO standards implementation are encapsulated in Section 4, succeeded by the presentation of findings and results. Then a comprehensive discussion to explore the impact of the applied changes is discussed in Section 5. Lastly, Section 6 concludes the paper by summarizing key insights.

## EXPLORATION OF BACKGROUND LITERATURE

Project-Based Learning (PBL) is an instructional approach in which students actively assume a central role in structuring their learning around well-defined projects, guided by educators (Haatainen & Aksela, 2021; Han, Yalvac, Capraro, & Capraro, 2015; Kokotsaki, Menzies, & Wiggins, 2016). According to Barab (2014); Savery (2019), PBL places a strong emphasis on context-specific learning, encouraging students to actively engage with real-world issues. Through interactive social exchanges and knowledge sharing, students not only address these issues but also achieve educational goals, fostering a deeper and more practical understanding of the subject. Robust research supports the efficacy of PBL in enhancing 21st-century skills and immersing students in authentic tasks (Bell, 2010; Haatainen & Aksela, 2021; Han et al., 2015; Kingston, 2018). These skills encompass critical thinking, problem-solving, collaboration, communication, and self-management skills (Viro & Joutsenlahti, 2020). In Krajcik and Shin (2014), the authors identified six key features of PBL. These include the introduction of a central question, a focus on learning objectives, active engagement in educational activities, collaboration among students, the use of scaffolding technologies, and the creation of tangible artifacts. The unique aspect of PBL lies in the development of artifacts

that address authentic problems, distinguishing it from other student-centered pedagogies such as problem-based learning (Amini, Setiawan, Fitria, & Ningsih, 2019; Anazifa & Djukri, 2017; Savery, 2019).

In Poonpon (2017), the author explored students' views on the integration of PBL into the language classroom, specifically through interdisciplinary projects (Warr & West, 2020). This work aims to motivate students to apply both their language skills and subject-specific knowledge in completing tasks. Students expressed their appreciation for the opportunity to apply their understanding of information science and English in these projects. They confirmed that engaging in these projects helped them recognize and enhance their English language skills in real-life scenarios. Ralph examined fourteen studies on PBL in STEM education, revealing favorable impacts on learners' knowledge and skills (Ralph, 2016). Students noted that PBL promoted collaboration and negotiation within groups, although some faced difficulties in maintaining motivation for teamwork.

The seamless integration of PBL into educational settings aligns harmoniously with the development of these crucial competencies, empowering students to navigate the intricate challenges of the 21st century with a scientifically informed perspective. This creative process requires learners to collaboratively find solutions to real-world problems, facilitating the implementation, application, and construction of knowledge. Facilitators, often in the roles of instructors and community members, play a crucial role in providing feedback and support to guide learners through their educational process.

## **OLD VS NEW: ASSESSMENT MECHANISMS & PROCESS**

The presented module uses the Project-Based Learning and design thinking approaches (DTPBL) following the CDIO process to help students practice the knowledge acquired in several modules, including Object-Oriented Programming in C++, Databases, Electronics, and Communication. In addition to consolidating existing knowledge, this module introduces new learning objectives focusing on design thinking and problem-solving. As such, it offers students a holistic learning experience, preparing them to apply their knowledge in real-life contexts and develop essential skills for tackling complex challenges. During the first session (phase Conceive), tutors assign students to 6 groups, each comprising 5 to 6 members, and engage in discussions regarding projects' themes.

To facilitate communication with students and the sharing of resources, the tutor establishes a Google Classroom and extends invitations to all students. To achieve the defined objectives, we have implemented two main methods to ensure continuous improvement. In the following subsections, we will detail these two experiences (the old and new assessment), emphasizing their notable differences. This comparative approach aims to provide an in-depth understanding of the advantages and disadvantages of each method, while highlighting the lessons learned from feedback. This in-depth evaluation process helps to guide our approach toward more effective and adapted pedagogical practices.

### ***The old approach***

The first method was implemented following the four phases proposed by the CDIO initiative, with a detailed schedule as follows. The "Conceive" phase lasts for 4 weeks, dedicated to assigning modules to team members and drafting the specifications (including functional and non-functional requirements). The "Design" phase spans 3 weeks and focuses on creating

graphic interfaces and designing the database. The "Implement" phase extends over 5 weeks, covering the development of basic (CRUD) and advanced features, embedded aspects, and concluding with the integration of various modules developed by team members to produce the final deliverable. Finally, the "Operate" phase, scheduled for 2 weeks, includes the technical and commercial evaluation of the delivered product.

The assessment of different learning outcomes was organized as follows: initial team validation to assess the quality of established specifications, communication skills, and the overall presentation. A second individual validation to evaluate graphic interfaces, the database, basic CRUD operations, advanced functional aspects, and the use of project management tools. A third individual validation to assess the integration of different modules by team members to achieve the final product, including the use of embedded hardware (Arduino Uno board, sensors, etc.). A fourth team validation was conducted to assess the student's ability to market their product and persuade the client. The final grade comprises two essential components: the individual grade and the team grade. The individual grade evaluates the skills acquired by each team member, while the team grade assesses collective work, assigning the same grade to the entire team. The calculation of the final grade is based on a weighting of 60% for the individual grade and 40% for the team grade. It is important to note that if the individual grade is below 10, the team grade is not considered in the final grade calculation. This grading system is designed to recognize both individual skills and the collaborative contribution of the team to the overall assessment.

### ***The new approach: criterion-referenced assessment***

Despite the growing interest in DT-PBL, it is challenging for educators to properly and legally evaluate the competency of each student. As we have seen in the old approach, the workload associated with the 4 validations was considerable, with a significant duration for each of them. In addition, major challenges arose in distinguishing the individual competencies acquired by each student, due to an overlap in the added value provided by different students. So, starting with the 2021-2022 academic year, we embarked on a new experiment, making significant changes to both the assessment process and process, to address the challenges encountered. This work led to a stabilized version adopted from the academic year 2022-2023. Details about the implementation of this new approach are presented in this section. The CDIO approach is built on the core premise that engineers should acquire practical skills via hands-on projects from the beginning of their education. The CDIO approach relies heavily on criteria-based evaluation to objectively and openly measure student achievement. This technique is based on pre-defined criteria that are connected with the core concepts of the CDIO standards and provide a comprehensive evaluation of learners' competencies. Unfortunately, developing a suitable assessment strategy remains an arduous task in the context of DT-PBL. This difficulty stems in particular from the complex nature of DT-PBL, which emphasizes active learning, concrete problem-solving, and collaboration between learners. Effective assessment must take these specific characteristics into account to accurately measure students' understanding and ability to apply the knowledge they have acquired. Given this reality, it is essential to promote the research and development of innovative assessment methods that better correspond to the principles of DT-PBL. This could involve collaboration between academics, educational researchers, and practitioners to design assessment tools aligned with DT-PBL's pedagogical objectives. Ultimately, while the challenge of finding an appropriate assessment strategy in the DT-PBL context is present, it also offers an opportunity to rethink and create approaches more suited to this innovative learning methodology.



Accordingly, a new detailed criterion-referenced assessment was proposed to evaluate the students' competencies. This assessment entails the evaluation of students based on 16 distinct criteria (learning outcome), outlined in Table 1. The assessment of competencies through a criterion-based evaluation mechanism, where several learning outcomes are defined, constitutes a rigorous and precise approach for measuring mastery of skills within a given domain.

The new evaluation consists of 7 principles Learning Outcomes (LO) distributed over the semester. Some assessment criteria are divided into more specific sub-criteria. This division makes the assessment more precise; and facilitates the identification of strengths and areas for improvement. It also allows evaluators to focus on specific aspects, making the assessment more controllable and promoting a more balanced evaluation. Besides, students will understand what is expected from them, thus facilitating their preparation and understanding of the assessment areas. Moreover, this approach will give students a better understanding of their skills and areas for improvement, helping them to make informed choices about their future specializations.

The first Learning Outcome (LO) and LO.7.1, LO.7.2, and LO.7.3 are evaluated in week 5, where students should present the application specifications including the main entities, the application's users, functional and non-functional requirements, and the suggested embedded features. Before starting the implementation, each tutor discusses the entities of the project's database, the attributes, and the relation between entities, based on various tutorials shared with the students in the Google Classroom. The criteria related to the project database (LO.2) are evaluated at the end of the "Design" phase. The assessment of the application development criteria, including the basic operations (CRUD), the advanced features, and the embedded aspect is distributed over five weeks during the "Implement" phase. During this phase, tutors guide students through pre-prepared workshops. For each stage of the development, a workshop containing foundational information is provided to the students. Most workshops are held asynchronously outside class hours. Subsequently, the students are expected to demonstrate proficiency in leveraging this information effectively and, incorporating design thinking principles to enhance and contribute their unique perspectives. During the "Operate" phase, the tutors evaluate the final application from different perspectives, including the proper functioning of all features, the GUI design, and the use of project versioning tools for integration. This evaluation is followed by a presentation of the application, where students have to prepare a marketing campaign.

Table 1. The criterion-referenced assessment

| Learning Outcome (LO)                                                       |                                                       | CDIO phase         | Assessment date   | Assessment tool           |
|-----------------------------------------------------------------------------|-------------------------------------------------------|--------------------|-------------------|---------------------------|
| LO.1: Define the application specification                                  |                                                       | Conceive           | Week 5            | Specification report      |
| LO.2: Build a relational database to guarantee data consistency             | LO.2.1: Elaborate the entity association model        | Design             | Week 7            | Document                  |
|                                                                             | LO.2.2: Elaborate the relational model                |                    |                   | Document                  |
|                                                                             | LO.2.3: Elaborate the physical model                  |                    |                   | Oracle Database           |
| LO.3: Project management                                                    | LO.3.1: Use a project management tool                 | All CDIO phases    | Every week        | Github todo list updated  |
|                                                                             | LO.3.2: Use a project versioning tool                 | Implement          | Week 7 to week 13 | Github repository updated |
| LO.4: Develop a management application                                      | LO.4.1: Develop basic operations (CRUD)               | Implement          | Week 8            | Desktop application       |
|                                                                             | LO.4.2: Develop advanced functionalities              |                    | Week 10           |                           |
|                                                                             | LO.4.3: Design the GUI                                | Operate            | Week 13           |                           |
|                                                                             | LO.4.4: Integrate a module to get a final deliverable |                    | Week 13           |                           |
| LO.5: Develop and integrate the embedded aspect in a management application |                                                       | Implement          | Week 12           | Arduino scenario          |
| LO.6: The cooperative working skills                                        |                                                       | ALL CDIO phases    | Every week        | Team cooperation          |
| LO.7: Idea presentation and critical thinking                               | LO.7.1: Argumentation                                 | Conceive + Operate | Week 5 + week 14  | Presentation              |
|                                                                             | LO.7.2: Prepare a presentation                        |                    |                   |                           |
|                                                                             | LO.7.3: Oral presentation                             |                    |                   |                           |
|                                                                             | LO.7.4: prepare a marketing campaign                  | Operate            | Week 14           |                           |

To foster collaboration while maintaining the importance of individual contributions, a learning outcome related to cooperative working skills is defined and evaluated every week starting from week 2. Since we are aligned with the CDIO standards, we gave great importance to project management skills. Accordingly, two learning outcomes were defined. The first one (LO.3.1), is a weekly assessment, that consists of evaluating a key skill that can considerably improve the students' efficiency. The second one (LO.3.2), is evaluated during the "Implement" phase, presenting the collaboration of all students in the preparation of the final deliverable.

The ultimate grade of each student is determined by aggregating the scores assigned to individual assessment criteria. Within criteria containing sub-criteria, the assigned score is the sum of the scores allocated to the sub-criteria. The score assigned to each assessment is communicated to students as an appreciation. This evaluation, referenced by criteria, adheres to a grading rubric where the appreciation attributed to evaluating the acquisition of different learning outcomes ranges from A (Excellent) to E (Not acquired), reflecting a comprehensive assessment of students' performance.

Table 2. Descriptions of both implemented methods

|                   | <b>Old approach</b>                                                            | <b>New approach</b>                                                                    |
|-------------------|--------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| <b>Process</b>    | Conceive: 4 Weeks<br>Design: 3 Weeks<br>Implement: 5 Weeks<br>Operate: 2 Weeks | Conceive: 4 Weeks<br>Design: 2 Weeks<br>Implement: 6 Weeks<br>Operate: 2 Weeks         |
| <b>Assessment</b> | Numeric<br>2 individual assessment<br>2 team assessment<br>Outcome-based       | Appreciation-based<br>5 individual assessment<br>2 team assessment<br>Competency-based |

Table 2 summarizes the main distinctions between the two approaches, examining both the project process and the assessment methods.

## **ALIGNEMENT WITH CDIO STANDARDS**

CDIO Standard 2: The DT-PBL pedagogical approach aims to develop essential learning outcomes such as the ability to analyze and synthesize information, develop effective solutions and communicate clearly and persuasively.

CDIO Standard 5: This module enables students to apply their knowledge and skills in real-life engineering situations, working on specifications; that meet concrete, potentially useful customer needs.

CDIO Standard 7: The exposed approach fosters close collaboration within a group of students, encouraging them to jointly solve complex engineering problems. It emphasizes the sharing of skills and ideas, creating an environment where each team member contributes collectively to overcoming the challenges encountered. The aim is to strengthen communication skills, encourage creativity, and develop the ability to work effectively in a team - all essential aspects in the engineering field. This approach offers learners an immersive learning experience integrating technical and interpersonal skills.

CDIO Standard 8: This project promotes innovative teaching and learning methods through the use of DT-PBL combined with blended learning and competency-based assessment. It therefore aims to create a dynamic educational experience. These methods promote competencybased assessment, enabling students to develop and demonstrate practical skills while adapting to a diverse learning environment.

CDIO Standard 11: The assessment approach introduced in the new method enables students to illustrate their learning outcomes and receive feedback on their performance, promoting

continuous improvement and personal development. In addition, students have the opportunity to self-assess through a criterion-referenced assessment approach, evaluating each learning outcome independently. This approach reinforces learners' responsibility and encourages in-depth reflection on their acquired skills and knowledge.

## IMPACT AND COMPARATIVE STUDY

In this section, we present an in-depth analysis regarding the impact of the changes made, observed between 2020-2021 and 2022-2023 academic year. We conducted this study using three samples, each comprising around 1,000 students, to provide a comprehensive perspective on the impact of these changes.

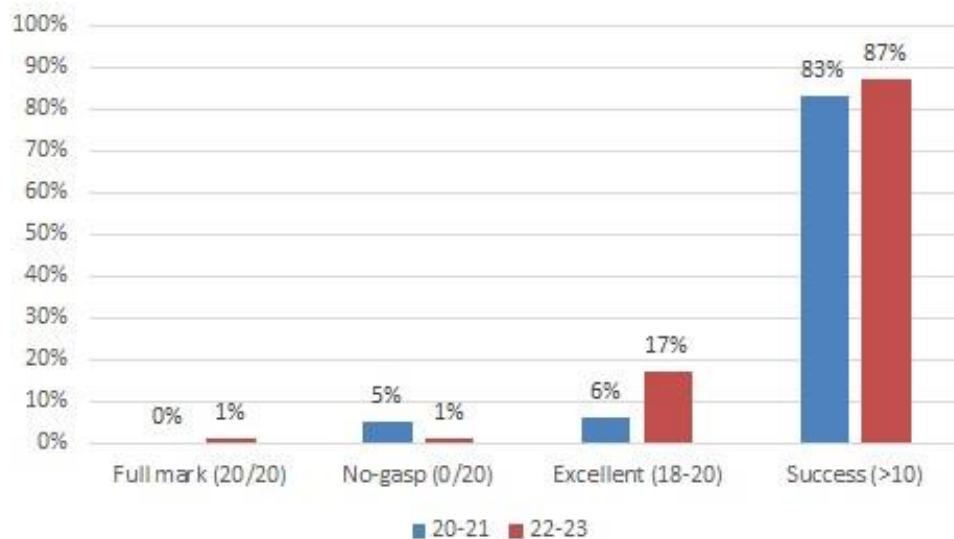


Figure 1. Impact of changes on student performance

Analysis of the results shown in Figure 1 presents a significant improvement in student performance. The no-gasp rate (0/20) decreased from 5% to 1% equates to a 5-fold reduction in the frequency of failures, suggesting a better understanding of concepts and a reduction in fundamental errors. Furthermore, the increase from 0% to 1% for full marks (20/20) can be interpreted as a significant improvement in the performance of a specific category of students. Indeed, given the size of the sample (around 1000 students), it is important to note that even a small percentage increase can represent a significant number of students having achieved this maximum mark. This implies a favorable trend, though attaining the highest score remains infrequent and poses a considerable challenge. Adopting the old approach, this mark was out of reach. Besides, the rise in the proportion of grades between 18/20 and 20/20, from 6% to 17%, suggests a marked improvement in student performance at the highest levels. This indicates a significant increase in the number of students achieving outstanding results in this grade range. This improvement can be interpreted as a positive sign that the new assessment method and changes are working, indicating more students have achieved high levels of mastery in their learning. In addition, the success rate (grade > 10) increased from 83% to 87%, indicating an overall positive impact on student performance. These results suggest that the new method helped to provide increased pedagogical support, and stimulate student engagement, thus promoting an overall improvement in academic results.

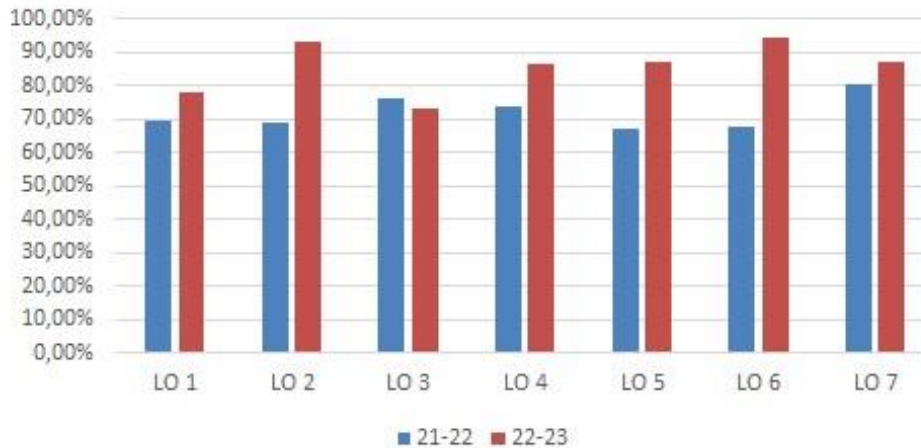


Figure 2. Learning outcomes acquisition rate

Due to criterion-referenced assessment, we were able to track the acquisition of skills by evaluating assessments. Figure 2 shows a comparison between the validation rates of our 7 learning outcomes between the academic years 2021-2022 and 2022-2023. We can see that improvement rates range from around 7% to 27% for all learning outcomes, except one (LO.3). In fact, we noted a 3% decrease in the learning outcome related to the use of version and project management tools via Git/GitHub and project boards. This variation suggests the need to explore the underlying reasons for this decrease, by examining student feedback and considering possible pedagogical adjustments to reinforce understanding of these specific concepts.

## CONCLUSION

This paper proposed a new approach to improve the assessment process of the intended learning outcomes in DT-PBL courses offered at the ESPRIT School of Engineering. The first approach is a result-based assessment, comprising three individual validations, which collectively contribute to 60% of the overall grade, while a team validation constitutes the remaining 40% of the final grade. In the new assessment approach, students are evaluated around 16 individual and/or group assessment criteria distributed throughout the semester. Accordingly, the new assessment provides better continuous feedback for the students and helps them to improve their learning process. The comparative study between both approaches has proved the effectiveness of the second one in enhancing the understanding and skills of the students. Given the increasing prevalence of Artificial Intelligence (AI), it became crucial to leverage this technology in the context of DT-PBL to foster students' creativity, encourage exploration of emerging fields, and equip them with relevant skills for a technology-driven professional landscape. Additionally, it is imperative to contextualize these projects within discussions on the ethical implications of AI and promote responsible use of this technology.

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# FLIPPED ASSESSMENT IN ENGINEERING MATHEMATICS

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## ABSTRACT

The CDIO framework provides extensive guidelines for improving engineering education quality, yet a critical gap exists in its Standard 11 - Learning Assessment. The framework's treatment of assessment quality enhancement is superficial, concentrating primarily on assessment 'of' learning (AoL) and neglecting the transformative potential of assessment 'for' learning (AfL). While the CDIO syllabus expresses a deep understanding of the importance of self-regulation (González, León, & Sarmiento, 2020) and identity affirmation for success in engineering education, their link to assessment is ignored. The study highlights the necessity for a cohesive integration and reinforcement between AoL and AfL, advocating for self-regulation as a key element of the latter. This is crucial especially in engineering mathematics where serious shortcomings have been identified. To spark a dialogue about the need to update Standard 11, this study presents a practical case from Finnish engineering education, demonstrating how Flipped Assessment (FA) has been specifically developed to facilitate the implementation of Flipped Learning (FL) in teaching of engineering mathematics. The study argues that simply evolving mathematics teaching cultures to align with CDIO standards is not enough; there is a critical need to revolutionize assessment practices as well. In an era where artificial intelligence is challenging conventional assessment paradigms, it is an opportune moment to critically reflect on the ethics of assessment and its validity. As an inherently ethical endeavor, the focus of discussion should shift from the technical validity of assessments to their normative validity. If assessment is detached from its role in nurturing students' mathematical identity and self-regulation, it may lead to engineers who are unprepared for the demands and expectations of their professional careers.

## KEYWORDS

Assessment of Learning, Assessment for Learning, Flipped Assessment, Flipped Learning, Engineering Mathematics, Standards: 2, 3, 11

## INTRODUCTION

The CDIO (Conceive, Design, Implement, Operate) framework (Malmqvist, Edström, & Rosén, 2020), which is built around a socio-cultural view of learning, offers comprehensive guidelines for enhancing the quality of engineering education, but framework's discussions on improving



assessment quality remain superficial. A critical gap exists in CDIO standard 11, Learning Assessment, which, in contrast to the overarching framework, relies on behavioral assumptions regarding learning and assessment. CDIO Standard 11 states the following: “Assessment of student learning is the measure of the extent to which each student achieves specified learning outcomes. Instructors usually conduct this assessment within their respective courses. Effective learning assessment uses a variety of methods matched appropriately to learning outcomes that address disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills, as described in Standard 2. These methods may include written and oral tests, observations of student performance, rating scales, student reflections, journals, portfolios, and peer and self-assessment.”

The standard advocates for the reliability and validity of the methods used to measure the extent to which each student achieves specified learning outcomes (Malmqvist et al., 2020). It acknowledges a spectrum of assessment methods, some of which, like observations and reflections, might be employed formatively. However, the predominant emphasis is on ascertaining terminal learning outcomes rather than utilizing assessment as a facilitator of learning. The prevailing strong psychological measurement paradigm in CDIO Standard 11 does not facilitate the integration of peer and self-assessment methods with self-regulation objectives. The standard predominantly addresses ‘assessment of students learning’ (AoL), thereby inadvertently marginalizing the dynamic capabilities of assessment ‘for’ learning (AfL) in nurturing student identity development (Barrow 2006) and enhancing self-regulation capacities (Brown & Harris, 2014). In the CDIO syllabus, the importance of self-regulation is emphasized in sections 2.4.3 (Adaptability, resourcefulness and flexibility), 2.4.6 (Self-awareness, self-reflection, metacognition and knowledge integration), 2.4.7 (Management of time and resources), 2.4.7 (Learning agility, lifelong learning and education), and 2.4.8 (Time and resource management). The strengthening of mathematical identity, which is connected to the fact that the individual sees himself or herself not only as a capable learner of mathematics but also sees mathematics as meaningful to him or her personally, asks especially the form of collaboration listed in sections 3.1.1 (Working in teams), 3.1.2 (Multi-perspective collaboration), 3.2.7 (Inquiry, listening and dialog), 3.2.8 (Negotiation, compromise and conflict resolution), and 3.2.9 (Advocacy).

Serious shortcomings have been identified in the teaching of engineering mathematics (Bennedsen, 2021; Peters & Prince, 2019). Peters and Prince (2019) noticed that engineering students are competent in procedural mathematics but the majority of them have problems in analyzing and resolving a simple engineering problem. They lack the skills to make assumptions, the ability to identify and select appropriate mathematical constructs to create an abstract model, and difficulties in interpreting the results of the model. Obstacles and anxiety in learning mathematics experienced by many engineering students (González et al., 2020) suggest deficiencies in the development of students’ mathematical identity. Observed poor self-regulation skills seem to be linked to a lack of teamwork skills and a limited ability to ask questions to solve a problem (Peters & Prince, 2019). To face the problem and strengthen the students’ self-regulation, there has been a shift from structured mathematics learning to more autonomous learning, where the learning of mathematics is implicit and not just a straightforward application of previously learned mathematical methods (Peters & Prince, 2019; Treveyan, 2014). What is still missing, however, is a shift from assessment models purely based on judgment to those that actively respond to and support students’ self-regulation.

This study responds to the lack of pedagogical debate on the assessment for learning (AfL) and increases the understanding of assessment from a sociocultural theoretical perspective. Flipped Assessment is introduced as a practical example and considered as a purposive cultural intervention for a development of assessment, which is informed and shaped by the values and history of the surrounding society and established school practices. From this perspective, discussing assessment merely as a method (practice or tool) is insufficient; it is also vital to consider its pedagogical rationales in alignment with the goals of CDIO. The CDIO syllabus thoughtfully emphasizes self-regulation as an essential learning objective, suggesting that it should be a fundamental consideration in the design of assessment practices.

## **ASSESSMENT FOR LEARNING AS A PIVOTAL INFLUENCER OF LEARNING**

Although assessment has been recognized as the most important influencer of learning and the summative exams have been identified as the Achilles heel for development of teaching (Rust, O'Donovan, & Price, 2005), assessment practices and research in higher education have still strongly drawn on the psychological measurement paradigm (Boud et al. 2018). The prevailing assessment practices are not dared enough to be questioned by both teachers and researchers (Nieminen, 2021). Changing the assessment approach from judging toward the goals of sustainable development and lifelong learning, which are also valued by the CDIO, is still in its infancy (Topping et al., 2023; Hansen & Sindre, 2023; Bennedsen, 2021).

Assessment is an ethical activity and the kind of discussion that is especially needed is a discussion that moves from the technical validity of the measurement to its normative validity. This involves not only questioning whether we measure what we genuinely value, or whether we measure what is easy to quantify, and finally whether we value what we manage to measure (Biesta, 2009), but also if assessment is detach from its role in nurturing students' mathematical identity and self-regulation, whether this lead to engineers who are unprepared for the demands and expectations of their professional careers. Especially in engineering mathematics, where mathematics as such is not important but mathematical identity development is crucial, teachers should have encouragement to take leaps toward AfL.

There are two cornerstone approaches to assessing student learning: AoF and AfL. AoL refers to the summative measurement of what has been learned, while AfL integrates assessment into the learning process. Although AfL and formative assessment are often considered synonymous, their theoretical basis is different (Baird et al., 2017). These days, the notion formative assessment has become a broad term under which almost any kind of assessment meant to support learning could be categorized (Swaffield, 2011). Initially, it has developed from behaviorist mastery learning theories (Bloom, 1968) and is more related to teachers as the initiators and guides of the process than students as learners (Black & Wiliam, 2009; Baird et al., 2017). AfL, instead, is in line with sociocultural approaches and is more related to students as guides of their own learning (Baird et al., 2017). It is particularly focused on encouraging student self-regulation (Hawe & Dixon, 2017).

To avoid misunderstandings, two other concepts should be distinguished, namely self-regulated learning (Pintrich, 2000; Zimmerman & Schunk, 2011) and self-directed learning (Knowles, 1975). Both involve students' active engagement and goal-directed behavior, but a "self-directed learner controls the learning trajectory as a whole, whereas a self-regulated learner's control is restricted to learning activity" (Cosnefroy & Carré, 2014, p. 4). Thus, the teaching of mathematics within the framework of self-regulated learning encompasses holistic learning objectives rather than solely focusing on mathematics-specific objectives (Toivola,

Rajala, & Kumpulainen, 2023). It emphasizes the completion of tasks, rather than directly addressing the objectives of mathematics learning. Consequently, the development of conceptual knowledge in mathematics is contingent upon the utilization of appropriate tools used within self-regulated learning.

Research literature has mainly focused on separation AoL and AfL into mutually exclusive entities based on differences in assessment activities (Taras, 2009; Baird et al., 2017; Bennett, 2011). As a result, two different types of assessment have emerged that do not integrate or support each other. Although AoL and AfL present the different functions of assessment, there is relationship between these two types of assessment and their functions overlap. AoL is always the first part of the AfL process and should not be relieved of all responsibility for supporting learning (Bennett, 2011; Taras, 2009). Likewise, AfL should not be relieved of the teacher's obligation to give grades. Of course, one might ask how justified grades are in engineering mathematics. Whether it be more appropriate than grading to ensure that everyone has sufficient mathematical skills to study engineering? To what extent does grading support or discourage teachers from improving their teaching of mathematics?

Despite efforts to redirect formal testing to reflect the pedagogical underpinnings of assessment (Brown & Harris, 2014), self-assessment within AfL strategies remains in the early stages of development. Self-assessment as a supporter of self-regulation has still received little attention although research suggests that self-assessment could significantly impact self-regulation (Andrade, 2019). In their reviewing literature study Broun and Harris (2013) found three major categories of students' self-assessment practices, namely self-estimation of performance, self-rating, and rubric based judgements. The categories contain procedures like using a model answer as a reference, integrating teacher-evaluation with self-evaluation, self-correction, using a computerized prompt system, self-selected reinforcements or rewards, contributing to the design of a scoring rubric, and judging the accuracy of answers to standardized test items. These all relate primarily to the AoL policies where the focus is on judging the products of students learning.

In general, teachers' discussions about AoL still revolve heavily around the summative exams that are thought to measure whether you have worked hard and studied what the teacher told you to study. Once the exams are positioned to the fundamental method of assessment, discussions about AfL are reduced to discussions of the quantity, timeliness, and effectiveness of feedback in engaging students in desired learning activities. From the socio-cultural perspective on learning, these discussions are limited in value as they are grounded in behaviorist assumptions regarding the nature of learning and its assessment (Shepard, 2005). Because the AfL is not for judging learning, but for learning this study does not follow the stream of research that emphasizes the need for realistic, veridical, or verifiably accurate self-assessment (Butler, 2011). Instead, the study focuses on self-assessment as a process that not only promotes achievement but also empowers students within teacher-driven assessment cultures.

## **FLIPPED ASSESSMENT AS A LEAP TOWARDS ASSESSMENT FOR LEARNING IN ENGINEERING MATHEMATICS**

This section presents the practical implementation of Flipped Assessment (FA) as a pedagogical approach to the AfL in engineering mathematics and considers its theoretical

underpinnings to support the development of Flipped Learning (FL). FA is a pre-planned assessment process that is rooted in a socio-cultural learning paradigm, where assessment practices support learning that is created by the learner and their social environment (Toivola, 2020). Throughout the process, students understand that assessment, like learning, is not an effortless process, but requires their active participation. More generally, FA in engineering mathematics supports students' growth as proactive and responsible engineers who understand that things do not happen by themselves but that they have the power to influence them through their own actions.

The context of this article is the Finnish education system, where teachers have high autonomy in both teaching and assessment. Finland has not adopted the internationally popular standards in school test-based accountability policies (Sahlberg, 2007). Initially since 2013, the author has been one of the Finnish FL pioneers at secondary school level (Toivola, Peura, & Humaloja, 2017; Toivola, 2016) and since 2015 developer of FA (Toivola, 2020). From 2021 onwards, the author has been implementing FL and FA in the teaching of engineering mathematics.

The starting point in developing FA in higher education has been that if a teacher has grading responsibility in mathematics, the assessment must be something that produces grades for students. Still, grading should by no means be the most important function of assessment. Grading should rather be considered as a secondary outcome. The main function must be on the pedagogical task of assessment: responsible teaching. In engineering mathematics responsible teaching does not only mean that students master the mathematics to be taught, but also mathematical competences required of engineers. For engineers, it is not mathematics itself that is relevant, but what they use mathematics for is. Companies are looking for engineers who can use mathematics as a tool for success; engineers who have the mathematical competence, the courage to innovate and the courage to fail mathematically in a way that leverages the learning of the whole community.

Initially, an examination of FL is imperative, which has become popular also among teachers in the CDIO network (Leong, Yee, & Kee, 2019; Gommer, Hermsen, & Zwier, 2016). An in-depth understanding of its objectives is essential, as it renders the discourse on FA purposeful and contextually grounded. There are two well-established terms referring to 'flipping', Flipped Learning (FL) and its' precursor Flipped Classroom (FC). FC refers to "an educational technique that consists of two parts: interactive group learning activities in the classroom, and direct computer-based individual instruction outside the classroom" (Bishop & Verleger, 2013, p. 5). FL was launched in 2014 as a response to the prevailing misconceptions among teachers, media, and even researchers about FC, which suggested that flipping was merely a teaching technique without any pedagogical foundation. "Flipped Learning is a pedagogical approach in which direct instruction moves from the group learning space into an individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter" (Flipped Learning Network, 2014).

Both FL and FC have been extensively meta researched as mathematics teaching methods that transform a traditional teaching paradigm (Fung, Besser, & Poon, 2021; Lo, Hew, & Chen, 2017; Naccarato & Karakok, 2015) but there is little research that pays attention to teachers as creators of FL and their pedagogical rationales while implementing FL. In their study Toivola, Rajala, and Kumpulainen (2023) found three main pedagogical rationales for FL in teaching mathematics, namely, individualizing learning, fostering self-regulated learning, and fostering

engagement. Individualizing learning emphasizes attempts to differentiate and humanize learning mathematics in heterogeneous student groups. Fostering self-regulated learning highlights the teachers' emphasis on students' responsibility in goal-oriented activity that is supported by self-paced learning. Fostering engagement is related to the teachers' attempts to create a personally motivating learning environment for students.

The author's FL practice in engineering mathematics is strongly based on self-paced learning. In every mathematics course, the units to be learnt are presented in a learning environment, supported with textbooks, exercises, correct answers, and instructional videos, which students go through by themselves at their own rate. Students can adjust their time use for each engineering mathematics course between two months and one academic year. Exam readiness is up to students too; each course has two mandatory FA procedures, with exam days available monthly. A significant structural change here is that the resources received will no longer be earmarked for individual courses. Instead, all resources will be pooled together for students to access, allowing them to use a maximum of 100 hours of teacher's guidance for any single mathematics course. In practice, rather than designating specific times for individual mathematics courses, the schedule features weekly 'mathematics in-class work'. The classroom is open to all students, regardless of their enrolled course, providing a collaborative space for study and guidance.

For a student, FA appears as a two-phase mathematics exam of varying levels, where 'you get a second chance' as you can return the same exam twice. The possibilities to schedule exams and choose the levels of the exams will encourage students to adjust and set their own learning goals, to develop control over their own learning, and to meet competence requirements. In the first 90-minute-long individual phase of the exam, the student's so-called 'failure-level' is determined. During this self-assessment phase, they take ownership of their assessment by setting targets for their desired exam grade. They have the autonomy to choose whether to take the exam at grade levels 1-2, 3-4, or 5, which is the highest grade in Finnish higher education. Every exam of different levels includes 7 tasks, and the failure-level is reached (the exam is passed as the level chosen) if at least 3 out of 7 tasks are correct. In this phase, the steps have been taken toward differentiation and humanization of learning mathematics in heterogeneous student groups. During the second 30-minute collaborative phase, students who have passed the exam work together with one or two peers undertaking the same level exam to improve their overall performance. In this collaborative peer-assessment phase, they collectively review the exam, identify and rectify mistakes, and strive to complete any remaining tasks. This phase is not just used to promote achievement but should be seen as an attempt to promote co-regulation by empowering students during the assessment and by motivating them to become learning resources of each other. The formative use of summative tests is manifested here when the students focus on areas of their weaknesses which they subsequently discuss with their peers. Simply identifying errors is not enough; for a task to be ultimately interpreted as correctly done, students must correct their answers and ensure that the teacher fully understands their corrections. The aim of this activity is not only to increase students understand the assessment process and focus their efforts on improving (Taras, 2009) but also to increase students' positive perceptions of themselves as learners of mathematics and to increase their understanding of the humanistic side of mathematics through their own mistakes (Borasi, 1994; Shepard, 2005). Still, the collaborative phase in FA is not compulsory. Students can continue to complete the exam for an extra 30 minutes on their own if they wish and return the exam only once. Overall, FA fosters a positive learning environment for mathematics, encouraging student engagement and treating mistakes as valuable steps toward self-regulation. It cultivates students' skills in monitoring and guiding their own learning, enhancing their understanding of their roles and responsibilities

in making informed choices in their educational journey. The final grading rules are as follows: For exams at levels 1-2 and 3-4, if 3 of 7 tasks are correct, the grade is 1 or 3 respectively. If 5 of 7 tasks are correct, the grade is either 2 or 4. For exam at level 5, if 3 tasks are correct, the grade is 4, and if 5 tasks are correct, the grade is the maximum 5.

FA requires a massive amount of preliminary work. Preparing mathematics exams that cater to various levels of competence is a tedious process for the teacher. During one academic year, the author conducted eight scheduled FA sessions, each of which offered the opportunity to take exams in several different courses. With 21 questions in one exam, this is a huge bank of mathematics tasks required for each FA session. To lighten the workload, artificial intelligence has been utilized to make different exam versions from the same exams. During the period, students completed up to three mathematics courses, which entailed participating in at least six FA processes. The most common number of courses completed ranged from one to two, yet there were also students who did not participate in any exams.

## DISCUSSION

This study contributes to novel insights into learning assessment in engineering education, particularly through the lens of mathematics education where serious shortcomings have been identified (Bennedsen, 2021; Peters & Prince, 2019). Although CDIO framework (Malmqvist, Edström, & Rosén, 2020) is built around a socio-cultural view of learning its standard 11, Learning Assessment, relies on behavioral assumptions regarding learning and assessment. While the issue of good engineering education is seen complex, shaped by social interactions and cultural contexts, learning assessment is viewed as a simple process driven by externally controlled reinforcement and punishment. Consequently, Standard 11 falls short in effectively fostering the development of self-regulated engineers, a fundamental aim of the CDIO standards. To meet the gap, the study introduces Flipped Assessment (FA), underpinned by socio-cultural theories of assessment for learning (AfL), as a purpose to broaden the discourse on assessment by providing a tangible, alternative method for evaluating engineering mathematics. In general, initiating critical discussions about assessment practices proves difficult, and there's a noticeable reluctance to question the status quo in these practices (Nieminen, 2021).

Instead of taking the grades easily given by teachers as the truth, we should cautiously consider not only their legitimacy, but above all what we are assessing, what they are used for and whether they are useful quantities for this purpose (Baird et al., 2017). Although there is evidence of the unreliability of teachers' grades (Falchikov, 2005; Leach, 2012; Brown et al., 2015; Andrade, 2019) and that final summative exams can be considered as a silent killer of learning (Mazur, 2013), there remains a reluctance to challenge the prevailing assessment of learning (AoL) paradigms. The idea that assessment is a formulaic process, which impartially generates grades, excludes the influence of teachers' personal opinions, and can be applied effectively at the conclusion of any learning event, is appealing to both teachers and students. Students, having become adept at navigating the terrain of summative exams, know precisely how to prepare for them.

A successful transition to AfL practices requires a clear understanding of the objectives of the new assessment approach and the methods to achieve them. FA prompts critical consideration of the extent of a student's responsibility in assessment and the ethical implications of seeking peer help to enhance grades. Rather than seeing the assessment responsibility being transferred to the students, FA should be seen as a shared control process (Kirschner and van

Merriënboer, 2013), where the teacher creates exams of varying difficulty, allowing students to choose their level of engagement. To prevent the exams from merely testing the ability to replicate known solutions, each level includes challenges that students are not expected to solve independently. Such tasks support the learning of mathematics in sustained and meaningful ways in collaborative learning situations (Kilpatrick, 2014; Shepard, 2005). Students need support to accept such challenges in assessment situations and to see setbacks as an essential part of their journey toward self-regulation. In FA similarities are sought with Carol Dweck's ideas about growth mindsets, which were told to the students during the introductory lecture. According to Dweck (2006), there are two kinds of mindsets: the growth mindset and the fixed mindset. In engineering, a growth mindset is crucial for innovation and problem-solving. A student with a growth mindset likes the challenges of learning and sees failure as an opportunity to improve. A student with a fixed mindset behavior is regulated by fear of failure, which may prevent the student from even trying and thus hinders the formation of collaborative learning environment. Students need to understand and accept that an exam serves its purpose in the AfL process only when it can identify areas needing improvement. It is a rather fruitless idea to use a measure that indicates that there is nothing to improve. An exam in which a student answers all questions correctly is, from a formative perspective, ineffective in fostering a collaborative learning environment and further advancing the development of self-regulation.

Like Flipped Learning (FL), FA requires students' own ability to take responsibility for their learning. FA may not reach students who struggle with setting deadlines or specific exam dates for their studies. In assessment situations, FA reveals the underachievement for students themselves. It appears that students who have neglected their studies do not gain much from the collaborative phase of FA, as they tend to either skip it entirely or associate with classmates who share their lack of preparation. Conversely, students who are motivated to achieve high grades make effective use of the collaborative phase and seem to enjoy it. For a teacher, it is incredibly rewarding to observe the positive dynamics of group activity that makes the idea of reverting to traditional summative assessments unappealing. Interestingly, not one student has shown interest in returning to traditional summative exams. Instead, the students seem to view FA as a privilege. This suggests that FA genuinely adds value to the educational experience and succeeds in redefining students' perceptions of assessment. In assessment situations, FA can highlight underperformance to students themselves. It seems that students who have neglected their studies benefit little from FA's collaborative phase, as they either skip it entirely or join peers with similar preparation levels. In contrast, students aiming for high grades effectively seem to utilize and enjoy the collaborative phase. For teachers, observing the positive group dynamics makes the thought of returning to traditional summative assessments unattractive. Although not all students have been satisfied with the use of FL as a teaching approach, it is noteworthy that not a single student has expressed a desire to return to traditional exams. After personal experience, students regard participation in FA as a privilege. This suggests that FA succeeds in enhancing the educational experience and changing students' perceptions of assessment. Further research is needed not only on the extent to which FA can support the development of self-regulation and the mathematical identity necessary for engineers, but also on the extent to which it affects students' goals for learning mathematics. The author will begin this empirical study next fall with new engineering students.

FA acts as a deliberate cultural intervention in the evolution of assessment, fitting with existing practices without challenging the traditional grading system. Thus, FA can be integrated into in-course assessments while still accommodating a final exam. In such a context, FA provides teachers with valuable firsthand insights into the effects of AfL on engineering mathematics education and offers fresh perspectives on potential advancements in assessment practices.

Concurrently, it is critically important to consider the pedagogical underpinnings of assessments that align with the CDIO goals. Given the lack of a reliable and valid method for measuring the achievement of CDIO objectives, our focus in CDIO Standard 11 should not be merely on AoF and how accurately we can assess the objectives outlined in the CDIO syllabus, but rather on AfL and how we can leverage assessment to facilitate the achievement of the CDIO framework's objectives.

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# **SUSTAINABLE MINDS: A LEARNING EXPERIENCE ENHANCING SUSTAINABILITY AWARENESS THROUGH A CHALLENGE-BASED APPROACH**

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## **ABSTRACT**

Contemporary youth will face an exacerbation of environmental, social and economic issues such as deforestation, natural resources use and poverty. According to the World Meteorological Organization report on State of Climate Services published in 2023, air pollution engendered 7 million deaths worldwide in 2020. To raise students' awareness about sustainable development goals, we organized an event on March 4-5 at ESPRIT School of Engineering, celebrating World Engineering Day for Sustainable Development. Our main goal was to emphasize the positive impact of engineers on shaping a more sustainable world. The event structure includes a hackathon, with key phases, starting with keynote speakers to explore critical learning outcomes, followed by an exploration of challenges related to specific united nations sustainable development goals (SDGs) (Nations, 2015). Teams were then engaged in focused design-thinking (DT) and problem-solving sessions, leading to the creation of prototypes. In today's ever-changing educational environment, the ongoing challenge is engaging students while fostering their creativity and critical-thinking skills. This paper delves into the realm of the "Sustainable Minds" Hackathon, a challenge-based learning (CBL) experience that involves faculty members, non-governmental organizations (NGOs), and industry partners. We aim to share our experience and provide valuable insights into the implementation of CBL in higher education, particularly in the context of promoting sustainability and meeting some of the SDGs. We therefore discuss the findings arising from the event, highlighting that the integration of CBL with SDGs marks a major step forward in higher education. This association goes beyond simply improving understanding of real-world challenges; it also underlines the importance of responding to society's needs and promoting responsible innovation.

## **KEYWORDS**

Challenge-based learning, Sustainability, hackathon, Innovation, Standards: 2, 3, 5, 6, 7, 8

## INTRODUCTION

Today, in an ever-changing higher education context, the ongoing challenge of engaging and inspiring students, while encouraging critical thinking, is more pronounced than ever. The present paper is a gateway into the exploration of a dynamic educational paradigm - the fusion of challenge-based learning (CBL) (Gallagher & Savage, 2023) with the CDIO standards (Malmqvist, Edström, & Rosén, 2020). A relentless search marks the current educational environment for innovative methodologies, and CBL stands out as a pioneer of transformative pedagogy. By turning students into active participants in their educational journey, it aims to overcome the limitations of traditional learning. As we engage in this exploration, the backdrop is a hackathon - an immersive experience that encapsulates the essence of creativity, collaboration, and real-world problem-solving, all centered on solving global challenges encapsulated in united nations sustainable development goals (SDGs). The following paper is not a theoretical exercise; rather, it's a living journey into the heart of the "Sustainable Minds" hackathon held at ESPRIT School of Engineering on March 4th and 5th, 2023. An event that serves as a learning and development paradigm, moving participants from passive learners to active contributors as they navigate through ideation, design, implementation and operation phases. As a result, the hackathon becomes the canvas on which CBL, CDIO principles, and the pursuit of the SDGs paint a vibrant picture of a redefined educational and learning environment. Looking ahead, our mission is twofold: firstly, to sort out the complexities of CBL in the context of CDIO, and secondly, to highlight the hackathon as a living representation of these principles. The paper is an invitation to educators and stakeholders alike, showcasing how a carefully organized hackathon, guided by the principles of CBL, CDIO, and a dedicated commitment to the SDGs, can potentially push engineering education to new and greater levels. The aim of this paper is not only to attract attention, but also to spark curiosity about the transformative potential at the intersection of cutting-edge pedagogy, CDIO's structured approach and the global impact anticipated by the SDGs. We explore the different aspects of "sustainable minds", aligning them with the global commitment to contributing to a sustainable and equitable future envisaged by the SDGs.

## BACKGROUND AND RELATED WORKS

CBL (Leijon, Gudmundsson, Staaf, & Christersson, 2022) constitutes a pedagogical approach rooted in the evolution of experience-based learning methods, which emerged over ten years ago thanks to John Dewey (1938; 1963) and were subsequently further developed in pedagogical approaches such as problem-based learning (PBL) (Krajcik & Blumenfeld, 2006). While PBL often seeks to deepen understanding of academic concepts, CBL is distinguished by a more real-world problem-solving approach, integrating values and adopting an entrepreneurial perspective to societal challenges. Both approaches offer unique opportunities for developing skills and preparing students to proactively address the complexities of the contemporary world. Improved skills in Conceive-Design-Implementation-Operation (CDIO) and conceptual thinking are possible through the effective implementation of DT (Brown et al., 2008) in engineering programs. This approach produces more competent and innovative professionals by leveraging innovative problem-based learning projects (Isa, Mustafa, Preece, & Lee, 2019). Therefore, it is essential to explore the integration of design thinking and strategic sustainable development. In Shapira, Ketchie, and Nehe (2017) the authors explore the fusion between design thinking and strategic sustainability. It looks at how these two approaches can be harmonized to foster more sustainable design processes. The authors examine possible synergies between design thinking, which focuses on creativity and innovation, and strategic

sustainability, which aims to integrate sustainable principles into organizational activities. The study offers insights into how this integration can lead to more environmentally and socially responsible outcomes. Furthermore, the transition from the CDIO model to challenge-based learning experiences offers an opportunity to enhance student learning while having a wider impact on society. This evolution in engineering education could have significant implications for the way programs are designed and delivered. In-depth study into the effective implementation of these new pedagogical approaches is essential to maximize the benefits for both learners and society as a whole (Kohn Rådberg, Lundqvist, Malmqvist, & Hagvall Svensson, 2020).

## EVENT STRUCTURE

The following section explores the entire structure of the event, focusing on the detailed planning and thoughtful insights that define its composition. Through the impactful ideas shared by the keynote speakers to the immersive problem-solving journey encapsulated in the hackathon, they all harmonize to create an educational symphony designed to respond to the principles of active learning, interdisciplinary collaboration and sustainable development.

### Registration and group training

Initiating Sustainable Minds is much more than just signing up; a comprehensive form is sent out, providing crucial information not only for administrative purposes but also for strategically forming collaborative teams.

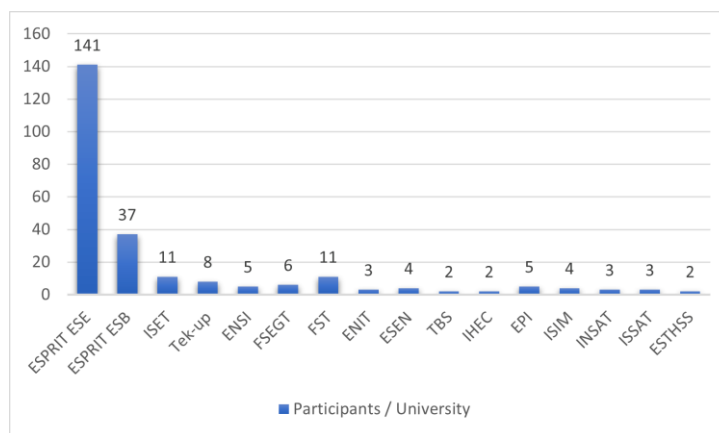


Figure 1. Universities diversity

What adds an extra layer of dynamism to this process is the conscious consideration of including participants from diverse universities, as shown in Figure 1, and varied fields of specialization. In recognition of the value of interdisciplinary collaboration, people from different fields actively contribute to the formation of these groups. Each group, made up of 3 to 5 members, represents a fine example of collaborative performance. The possibility of including a coach further enriches the learning dynamic, providing industry insight and mentoring. And for those without pre-formed groups, a matching process was implemented. Our process ensures that each team represents not only a diversity of skills but also a range of academic backgrounds, to ensure a blend of perspectives.

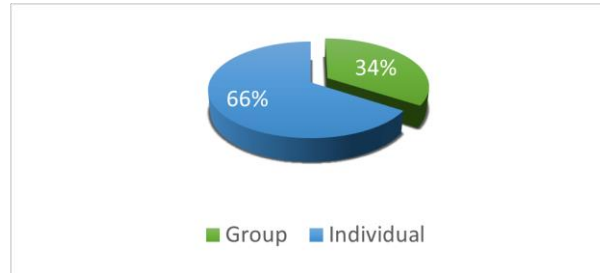


Figure 2. Group vs. individual subscription

As Figure 2 shows, the rate of individual registrations significantly exceeds that of group registrations. This observation suggests that participants showed a marked interest in registering independently rather than as part of a group. This preference can be interpreted as a potential inability to form teams and work collaboratively. The formation of groups was strategically envisaged to promote teamwork while taking into account the diversity of participants' skills, as detailed in Figure 3. Integrating this diversity aims to maximize individual strengths and offset probable weaknesses, thus contributing to a more complete and balanced learning environment.

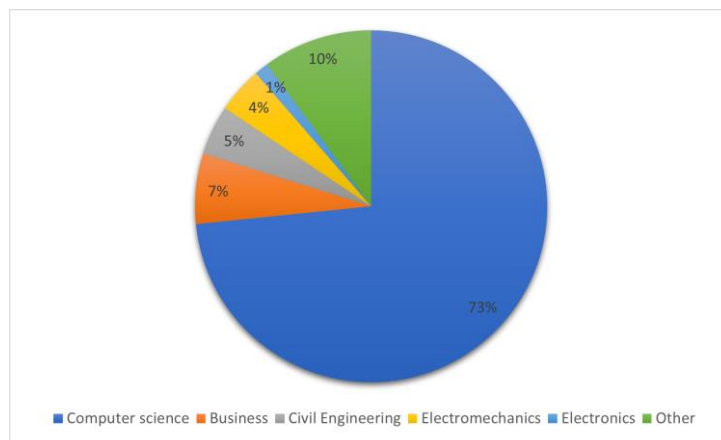


Figure 3. Diversity of participants' skills

In addition, to facilitate the harmonious integration of group members and stimulate collaboration, team-building activities have been specifically designed. These activities, based on playful games related to sustainable development, go beyond simple group formation, fostering a cooperative, interactive, and committed learning environment. This strategic approach aims to maximize the effectiveness of the teams formed while offering an enriching and stimulating learning experience for all participants.

### **Keynote speakers and exploration of SDGs**

An essential part of the "Sustainable Minds" journey is for participants to immerse themselves in the wealth of knowledge shared by keynote speakers, selected to represent a wide range of expertise. Beyond industry, this event expands its focus by inviting speakers from the dynamic world of technology and social engagement. Such deliberate inclusion reflects the fact that engineering challenges are not limited to only technical complexities. Instead, the intersection with societal needs, community engagement, and innovative technology becomes a key focus. The keynote speakers bring valuable insight from a wide perspective, which aligns perfectly

with the CDIO framework's focus on integrated learning experiences. The key sessions, enriched by the diversity of the speakers, revolve around an exploration dedicated to the SDGs. For instance, the first speaker addresses the intersection of environmental responsibility with digital transformation. The second speaker focuses on Corporate Social Responsibility (CSR) initiatives. The third speaker highlights the significance of quality education for fostering sustainable development. Finally, the integration of technologies to advance sustainable agriculture is discussed, offering unique perspectives on shaping a more sustainable and technologically advanced future.

### ***Challenge announcement: Sustainable universities***

The highlight of "Sustainable Minds" takes place with the exciting announcement of the challenge, representing a departure from traditional competitions. The challenge is not merely an academic exercise, but a call to action, responding effectively to the theme of the university's responsibility to sustainable development. Precisely designed, it acts to guide participants toward innovative solutions for promoting sustainable development in the university environment. Besides being tasked with solving complex technical problems, participants also engage in an exploration of the university's central role in promoting sustainable development. As part of the challenge, they are invited to consider and implement ideas that extend their thinking further than engineering problem-solving, into the realms of social and environmental responsibility. They face both the challenges of engineering and the more general question of how universities can be agents of positive change. Once the challenge has been announced, participants proceed from theoretical understanding to the practical application of engineering principles.

### ***Design thinking workshops: Foster innovation***

Before tackling the challenge, competitors have the opportunity to take part in a preparatory phase - a design thinking workshop. It provides participants with invaluable tools for solving complex problems and designing innovative solutions. Design Thinking Workshop isn't a typical course; we created an interactive area where creativity and innovation take place side by side. Participants worked their way through an interactive session that encouraged them to think "outside the box" and move from traditional problem-solving approaches, to build skills and confidence to tackle diverse challenges.

### ***Kick-off hackathon***

As participants step into the hackathon arena, they bring with them a symphony of ideas gathered from industry experts, as well as a profound understanding of the societal challenges encapsulated in the SDGs, and the problem-solving skill cultivated by design thinking. This combination of knowledge forms a solid basis on which participants can build their engineering solutions for a sustainable university.

### ***Random draw: Integrate the designed SDG***

In the middle of the hackathon, participants were confronted with an exciting surprise: the SDG random draw. At this point, participants proceeded to a random draw, selecting specific SDGs except SDG 4 (quality education). Their task was clear: each team had to integrate the chosen SDG into their current solution. This unexpected element introduced an innovative layer of complexity, which forced participants to quickly adapt and integrate a new dimension into the design process. This unannounced integration of the SDGs reflects the agile problem-solving

skills recommended by the CDIO framework. Besides being a challenge, this initiative was also an innovation and adaptability stimulator. They were challenged to be creative and to think not only about their initial project but also about how they might integrate the designed SDG into their projects.

### ***Evaluation Phase: 20 juries***

Sustainable Minds reached its high point through an exhaustive two-phase evaluation of the participants' ideas, a process that involved 20 expert teachers from ESPRIT in various fields of the presented projects to assess the proposed solutions and enhance their value through evaluation. The evaluation criteria during phase 1 included several key aspects to assess team performance. Idea generation scored 15 points, focused on adherence to the hackathon theme and objectives, aligning solutions with the CDIO standard 5 (Design-Implement Experiences). Innovation and creativity, assessed on 10 points, focused on the degree of originality of the solutions, in line with the CDIO standard 8 (Active Learning). Impact on the SDGs, rated out of 25 points, introduced an innovative approach, awarding points according to the number of SDGs addressed, in line with the CDIO standard 2 (Learning Outcomes). Presentation quality, assessed on 20 points, focused on clarity, conciseness, and compelling content, in alignment with the CDIO standard 7 (Integrated Learning Experiences). Finally, implementation and adaptability, each scored 15 points, considered solution demonstration and ability to meet challenges, corresponding to CDIO standards 3 (Integrated Curriculum) and 6 (Engineering Learning Workspaces), emphasizing practical experience and adaptability. These overall criteria ensured a comprehensive assessment of the teams' performance in the hackathon context. The six highest-ranked teams from the first evaluation were selected to participate in the second phase of the presentation, where they faced a shorter deadline, limited to a threeminute presentation. The submissions were evaluated by five experts according to identical, comprehensive evaluation criteria, to identify the three most outstanding solutions. Evaluation criteria included relevance, measured by the clarity of the identification of a distinct need contributing to the university's sustainability, and originality, assessed by the degree of innovation and originality of the suggested solutions. The overall impact of the project, beyond short-term considerations and beneficial to the environment and the university economy, was another essential criterion. Finally, the quality of the presentation was also taken into account, based on clarity, conciseness, and persuasiveness in communicating the project's objective. The three teams with the highest overall scores won, not only by triumphing at the hackathon but also by demonstrating outstanding achievements in developing sustainable solutions for the university. These winners demonstrated the innovation, originality, and relevance of their engineering solutions, setting a high standard for the transformative potential of CBL events.

Figure 4 provides a schematic overview of the process evaluation stages and criteria.





Figure 4. Evaluation process

## ALIGNEMENT WITH CDIO STANDARDS

CDIO Standard 7 (Integrated Learning Experiences): Forming diverse groups, including participants from different specialties, encapsulating the best of integrated learning experiences. The purposeful organization of diverse teams reflects the collaborative environments of authentic engineering challenges, where individuals from different disciplines come together to solve multifaceted challenges.

CDIO Standard 2 (Learning Outcomes): The purposeful presentation of the SDGs enhances the learning outcomes for participants. Attendees gain an understanding of the societal context in which their engineering solutions will operate. Such an alignment ensures that the educational journey goes further than technical skills, giving participants a sense of responsibility and awareness of the wider implications of their future engineering projects.

CDIO Standard 5 (Design-Implement Experiences): Once the challenge has been announced, participants proceed from theoretical understanding to the practical application of engineering principles.

CDIO Standard 8 (Active Learning): During the hackathon, learning was not a matter of passively receiving information, but rather an active, interactive process. Participants are engaged actively in problem-solving methodologies, developing their thinking skills and adopting a proactive learning approach to shape the sustainable solutions that will define the "Sustainable Minds" hackathon. Furthermore, the design thinking workshop was used as a model of active learning.

## INTERSECTION OF CBL AND SDGs: SUSTAINABLE MINDS IMPACT

We believe The intersection of CBL, pedagogy, and SDGs represents a transformative approach to education, in which traditional boundaries become overcome in favor of an engaging learning experience. As a pedagogical approach, CBL reshapes the education environment by placing students at the center of their learning experience. This approach reaches for more than traditional knowledge transfer, promoting critical thinking, problem-solving skills, and collaborative abilities. This impact was profound through the event, creating an environment where students move from passive learners to active contributors, in alignment with SDGs. It goes further than academic success. It extends to the development of a mindset that is both socially aware and environmentally responsible. Through CBL initiatives related to the SDGs, students become active contributors to sustainable solutions. The connection between CBL and the SDGs becomes evident when students take on concrete challenges, using the SDGs as a guiding tool for their projects. Through strategic alignment, each CBL initiative becomes an example of sustainability, addressing specific SDGs and developing a sense of responsibility for global issues. Through the intersection of CBL, pedagogy, and SDGs, the winning projects are proving to be invaluable tools. By exploring these projects in detail, we highlight the alignment between challenge-based learning and the Sustainable Development Goals, demonstrating the real impact of this educational approach on sustainable development and societal improvement.

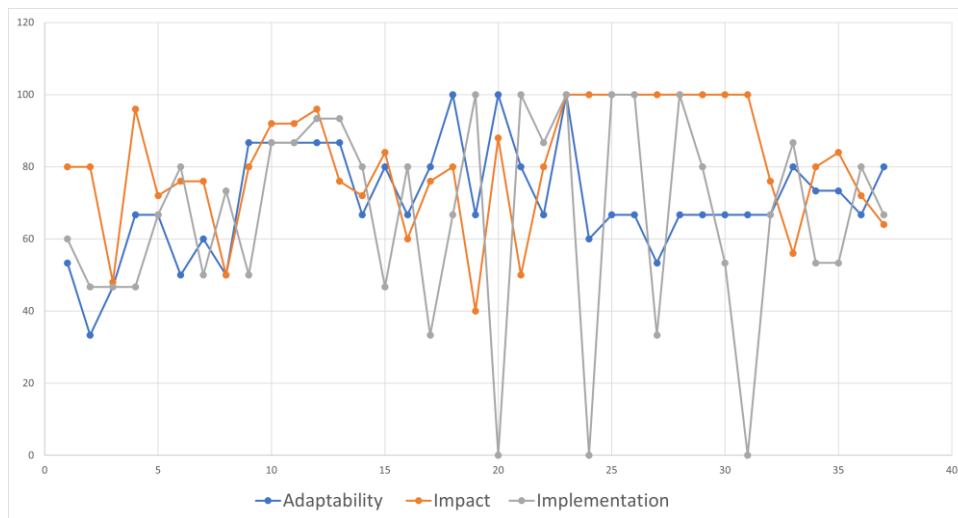


Figure 5. Teams performance comparison: Phase 1

Figure 5 shows the performance of all teams in terms of adaptability, impact, and implementation. Each data point on the graph corresponds to a team, and its position indicates the points reached in these three aspects. The results show that, on average, the teams demonstrated a good capacity in terms of adaptability to the encountered challenges and an overall positive impact on their projects, but a certain variability in the quality of the implementation of their solutions. Due to time and skill constraints, certain teams were unable to progress beyond the ideation phase and were limited to proposing innovative ideas. These data could suggest specific strengths and areas for improvement, enabling further reflection on the adaptive aspects, overall impact, and effective implementation of the proposed solutions.

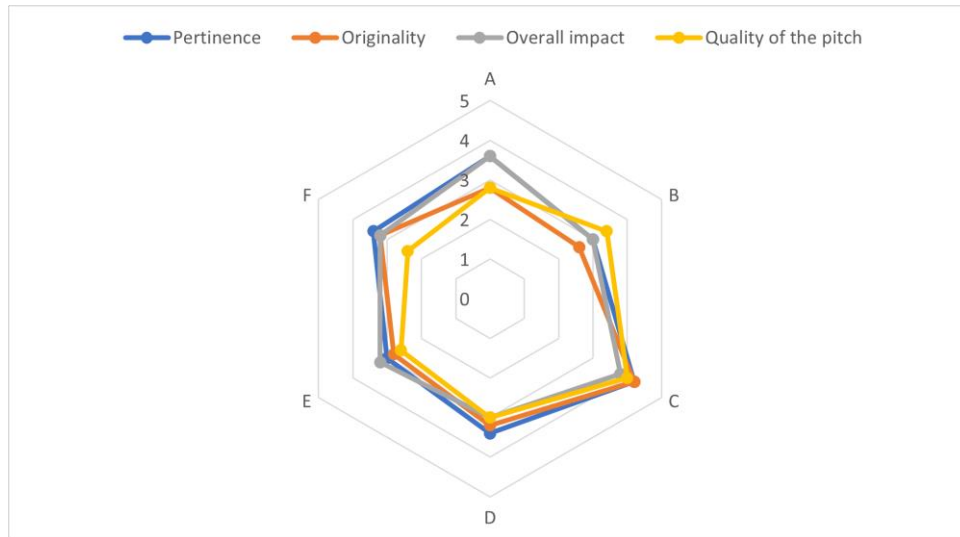


Figure 6. Teams performance comparison : Phase 2

Figure 6 provides an easy visual overview of each team's performance, helping to identify their strengths and improvement targets as part of the hackathon evaluation. Team C stands out for its performance, while others may consider refining specific aspects of their projects.

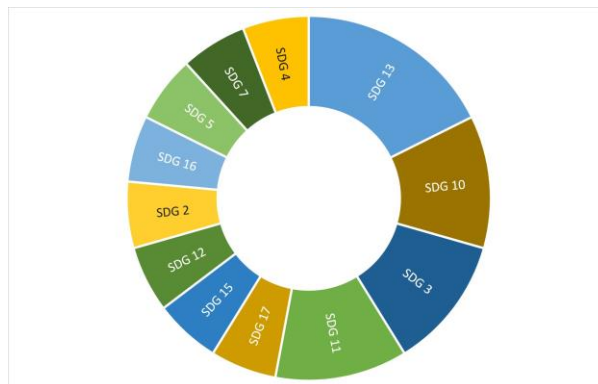


Figure 7. Overall impact on SDGs

In Figure 7, we illustrate the project's impact on the various SDGs (Nations, 2015) according to their frequency of use. The focus is on SDG 13 (Climate Action), followed by SDGs 11 (Sustainable cities and communities) and 3 (Good health and well-being). The chart shows the different contributions made, highlighting the alignment of projects with the various SDGs for a comprehensive approach to sustainability.

## CONCLUSION

In conclusion, CBL's exploration within the context of CDIO and its alignment with the United Nations' Sustainable Development Goals (SDGs) through the "Sustainable Minds" hackathon reveal a transformative educational environment. The presented projects highlight CBL's ability to meet real-world challenges. As educators, this journey encourages a review of traditional

approaches, promoting CBL as a key facilitator of pedagogical innovation. The impact of the SDGs, demonstrated in various projects, emphasizes the societal importance of these educational efforts. This journey through "Sustainable Minds" reflects CBL's transformative potential and invites us to align engineering education with global challenges and goals. As part of this challenging higher education environment, the convergence of CBL and the SDGs represents a step towards an engineering education that promotes positive societal impact and responsible innovation.

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# FROM STUDENTS' EVALUATION OF AI TEACHING TO TEACHERS' SKILLS ENHANCEMENT

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## ABSTRACT

For a while, training needs were identified by supervising teachers based on a personal effort using a short-term and punctual strategy. Programmed training could respond to current teachers' needs, with practical and hands-on training that can be applied directly with students and organized on site. Despite supervising teachers' efforts to implement targeted training programs, there are discrepancies between student opinions and teaching objectives. This finding remains valid and stems from the fact that training needs have never emerged from the results of student evaluation of teaching (SET) survey. Through this paper, our aim is to start from the SET process to generate training needs for Training of the Trainers (ToT) programs for a better-quality teaching that is effective for both teachers and students involved in the curriculum. In fact, the process of the SET begins by collecting students' opinion on AI teaching through many questions. Responses are related to different degrees of students' satisfaction. After that, an analysis of results is done with different indicators such as a visualization of results by class, by course or by teacher. For each indicator, measures are used to determine if it is necessary to take decisions by proposing adequate training. The selection of an indicator with measures is considered as a scenario. Scenarios can be defined by combining more than one indicator. The execution of these scenarios leads to recommendations for future professor's training. In this way, we can consider that we are aiming to achieve standards 9 and 10 by addressing standard 12.

## KEYWORDS

Student Evaluation of Teaching, AI courses, Generating training needs, Skills enhancement, Standards: 9, 10, 12

## TRAINING OF TRAINERS FOR TEACHER'S PROFESSIONAL DEVELOPMENT

Teaching is one of the areas of professional activity of university teachers, alongside research, supervision, and university administration. In most higher education systems, teachers in higher education are trained almost exclusively in research, which means that their expertise in other areas of their professional activity is usually developed in workplaces and educational spaces with, on the one hand, teachers via available sharing channels and on the other hand

students conferring on various learning situations to adapt to a dynamic and sometimes restrictive professional environment.

Historically, a teacher's professional development has depended on mechanisms such as reflective practice through the systematic analysis of his or her actions and experiences with a view to identifying principles that can guide any future improvement action (Brookfield, 1992; Calderhead, 1992; Kolb, 1984; Schön, 1983; Zeichner & Liston, 1996). With the evolution of research in this field, the professional development of university teachers essentially consists in the construction of the competencies and identity transformations in work situations during a career (Paquay and al., 2010). In a system where teacher training is institutionally unformalized, professional development is primarily a matter of voluntary intervention. Indeed, university teachers devote time to reflecting on their practices and their impact on student learning to draw out principles that will help them build their pedagogical knowledge base.

This area of research is attracting growing interest in higher education institutions, which are increasingly keen to promote ToT programs to improve the quality of teaching and learning and meet the challenges of student-centered learning (Gaebel, B.M. and al., 2018). In addition, studies have identified the characteristics of effective professional development programs based on a review of recent studies of professional development models (Darling-Hammond and al., 2017), describing the types of professional development that lead to robust professional learning, improved teaching, and deeper student learning. On the other hand, other research focuses on ToT programs assessment by teachers. These methods involve the identification of certain key design factors with reference to well-defined indicators to facilitate the understanding and conceptualization of tasks and activities that should receive greater attention when designing a faculty professional development program (Muammar and Alkathiri, 2021). At our level, our study is rather interested in generating teacher training needs before the design of programs dedicated to them based on the students' evaluations of teaching.

## **GENERATING TRAINING NEEDS FROM THE STUDENTS' EVALUATIONS OF TEACHING**

Despite efforts to support teachers' professional development, the SET has been reduced to an isolated bureaucratic procedure, disconnected from a global approach to quality that values and supports teaching (Cashin, 1996; Bernard and Bourque, 1999, Fontaine, 2009; Younès and al. 2012). To date, the SET procedure is limited to a collection of individual assessments, blurring singular points of view and discrepancies by reducing them to satisfaction statistics for sharing feedback with students to complete the evaluation procedure of the teachings on their side. And yet, the procedure feeds on different forms of sharing, the pooling of meaning between the different actors -students, teachers, managers-. Indeed, student feedback obtained within the SET framework can yield information that is most helpful to teachers, particularly when combined with other data like exam results, the teacher's own annotations, or teaching experts' observations (Bernard and al., 2000; Coggi & Maccario, 2009; Paulsen, 2002; Smith, 2008).

A more recent analysis of the scientific and expert literature shows that the SET can become one of the strategies to support the professional development process of university teachers and thus act in complementarity with other strategies such as the steering and monitoring committee, the council of the direction of studies or research applied to university education (Berthiaume and al., 2011; Younès and al., 2017; Fernandes and al., 2023). Through our study, we have based ourselves on literature models to reconcile methods of generating training

needs for trainers with the basic principles of the design of the SET model, for quality teaching, through an experimental sample specific to AI teaching.

Indeed, we present the results of the SET, through a reliable program evaluation method to implement a systematic and continuous improvement based on continuous program evaluation results (Standard 12) and consequently refine the pedagogical and technical skills of the teacher with a view to improving learning. Further, and based on these results, we provide evidence of systematic and continuous improvement (a) to set up a process for generating teachers' teaching skills (Standard 10) and, (b) to systematically support the development of teachers' skills to best meet the needs of accompanying students in a dedicated context (Standard 9).

## THE INTENT OF OUR APPROACH

We have discussed in earlier parts how SET and ToT processes directly affect the quality of teaching. We have concentrated on how these two activities might interact because they have the same goal, which will enhance teaching practices. This concept is illustrated in figure 1. We have only developed one direction of interaction in our work, which is the determination of necessary training through student response analysis.

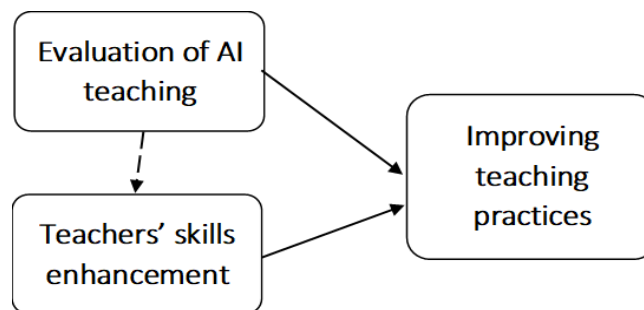


Figure 1. Intent of our approach

Our study is reserved for the analysis of feedback from students who follow AI courses aimed at generating training needs for teachers responsible for teaching the targeted courses.

## METHODOLOGY

Although the interaction between the two activities in Figure 1 appears simple, Figure 2's description of the process reveals that it involves numerous consecutive steps. We have implemented components for some steps to provide some outcomes automatically. That's why this process is considered partially automated. The sections that follow will cover further details.

Following the process of gathering data from an online assessment platform, indicators are chosen in the predefined scenarios through a visualization step. After that, we go through these scenarios to start the data analysis step manually. Lastly, we move on to generating recommendations for the training needed.



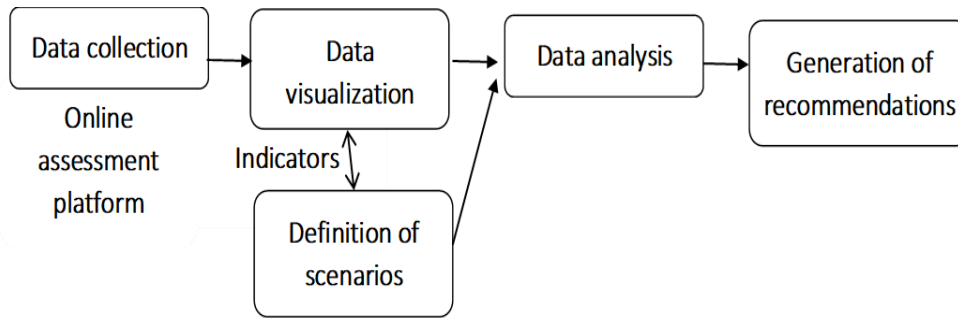


Figure 2 Process of our methodology

### Data collection

The information was gathered using a numerical survey that students were given at the end of their study session. This survey corresponds to every course offered during this period. However, we have limited our attention to AI courses. The following is a description of the technical and pedagogical aspects of teaching that are covered in this survey:

Table1. Survey for SET

|                                                                                                           |                    |
|-----------------------------------------------------------------------------------------------------------|--------------------|
| 1. Course presentation (module sheet, learning outcomes, and assessment methods)                          | 1 2 3 4            |
| 2. Adopted pedagogy (method, justification, response to questions, and rhythm)                            | 1 2 3 4            |
| 3. Adapting learning activities to satisfy the course's goals (innovation and pertinence)                 | 1 2 3 4            |
| 4. The course-related workload (in hours) outside the scheduled class time per week                       | 1 2 3 4 5<br>6 7 8 |
| 5. Accomplishment of learning objectives (mastery of the learning outcomes specified in the module sheet) | 1 2 3 4            |
| 6. Availability of teaching resources in the classroom                                                    | 1 2 3 4            |

|                     |                |             |                  |
|---------------------|----------------|-------------|------------------|
| 1 Very dissatisfied | 2 Dissatisfied | 3 Satisfied | 4 Very satisfied |
|---------------------|----------------|-------------|------------------|

### Data visualization

The students' responses to the courses are automatically displayed. The visualization is presented based on various indicators to assist the analysing process. To get an idea of the overall number of answers for each question and the proportion of responses for the six levels of satisfaction we could start by launching a global visualization. After that, the visualization can only refer to the teacher indicator to get insight into the corresponding answers for each of their courses. To select a particular course for the teacher in question, we can add the indicator Course in a third step. Other indicators, such as Class or level of study, can be also employed.

### Scenarios

As previously noted, by specifying a certain visualization sequence, combinations of indicators are available. A scenario is described as an ordered set of indicators with a minimum percentage of answers for each question. A scenario with multiple indicators is considered

complex. For instance, the indicators Teacher-Course could create a complex scenario. If the goal is to confirm the degree of satisfaction with the adopted pedagogy (question 2 of the survey), we set a minimum response rate of 60% for the level of satisfaction 3: Satisfied (at least 60% of the course participant choose this specific answer). This indicates the rate of satisfaction of the pedagogy that a particular teacher has chosen for a particular course.

### Data analysis

The data analysing step is conducted manually by applying a scenario on the visualized data. As mentioned before, scenarios have a minimal response rate based on how satisfying a query is. Future training recommendations will be defined if the response rate obtained falls below the minimum required and relates to a scenario with indicators such as Teacher or Course.

### CASE STUDY

After one semester of education, our school has just begun using the survey found in section 2-1 for SET (Standard 12). As mentioned, we have automatically created a visual representation of the data using several indicators. There were 820 students that completed the survey in total, and 3476 course assessments were completed. By following these steps (Figure 3), we have implemented the process shown in Figure 2.

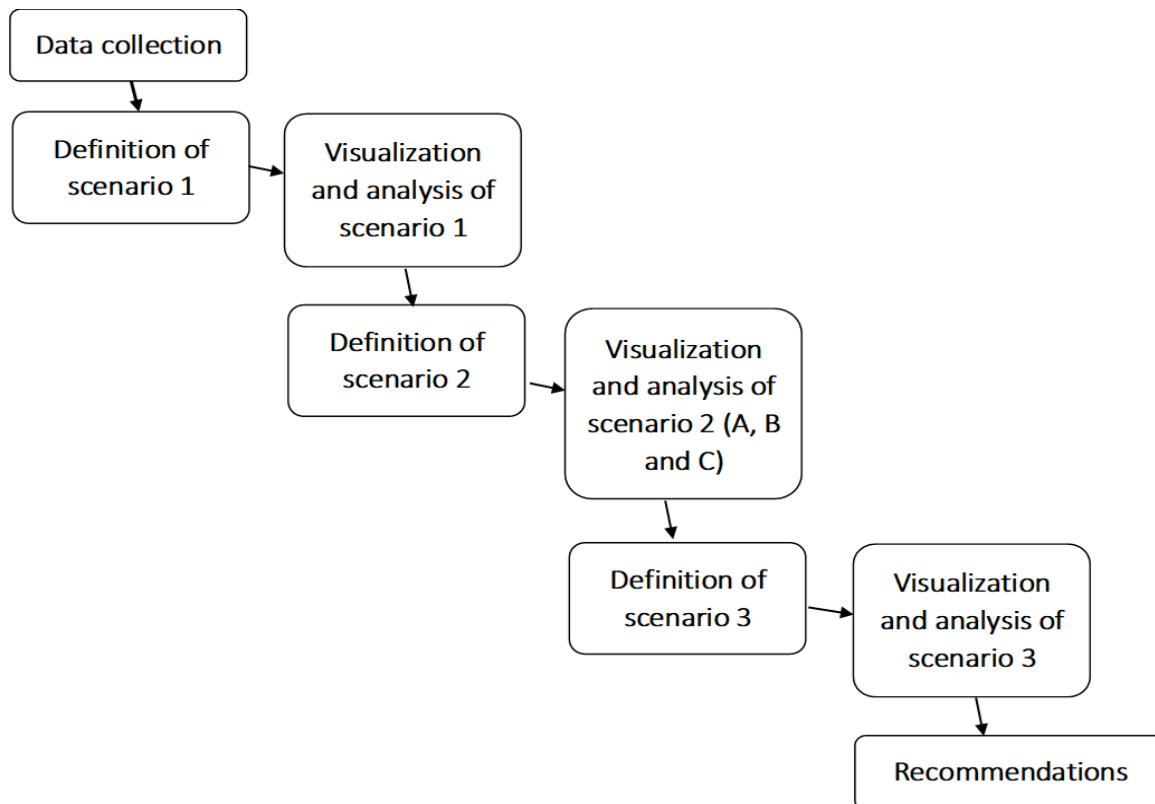


Figure 3. Steps of the case study

We only observed one instance of an AI course in our case study. Our goal is to analyse the percentage of students who are satisfied with the pedagogical aspects. Consequently, for

questions 2 (see table 1), the minimal rate of satisfaction (level 3 and 4 of the table 1) was defined at 60%. This scenario was constructed to give a general overview of the adopted pedagogy of this course.

Table 2. Scenario 1 of the indicator Course

| Indicator | Question                                                                       | Level of satisfaction             | Rate of the level of satisfaction |
|-----------|--------------------------------------------------------------------------------|-----------------------------------|-----------------------------------|
| Course AI | 2. Adopted pedagogy (method, justification, response to questions, and rhythm) | 3- Satisfied<br>4- Very satisfied | 60%                               |

We have obtained a rate of satisfaction equal to 12.5% as shown in Figure 3 below.

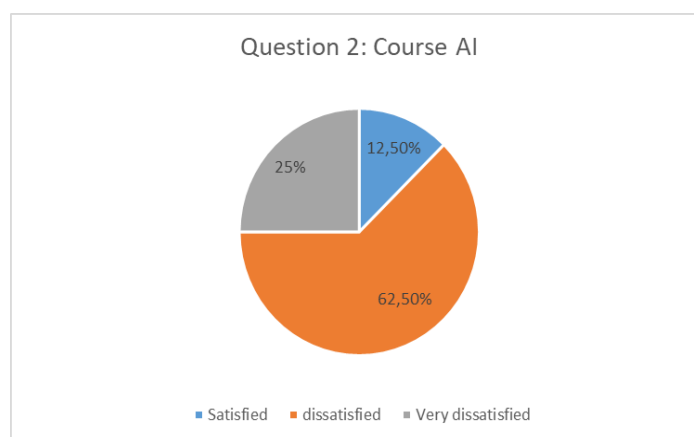


Figure 3. Visualization of scenario 1

This is an extremely low rate. For this reason, we have attempted to analyse the associated teachers' evaluations for these six fifth-level classes. Three of our teachers—A, B, and C—are involved in this teaching.

We can estimate that these teachers need their pedagogy to be improved for the specified targeted AI course. We created another scenario with the indicator Teacher to confirm this assumption. A summary of each teacher's pedagogical aspect is provided by this scenario.

Table 3. Scenario 2 of the indicator Teacher

| Indicator                   | Question                                                                       | Level of satisfaction             | Rate of the level of satisfaction |
|-----------------------------|--------------------------------------------------------------------------------|-----------------------------------|-----------------------------------|
| Teacher "Sample of teacher" | 2. Adopted pedagogy (method, justification, response to questions, and rhythm) | 3- Satisfied<br>4- Very satisfied | 60%                               |

We have obtained these three results below.

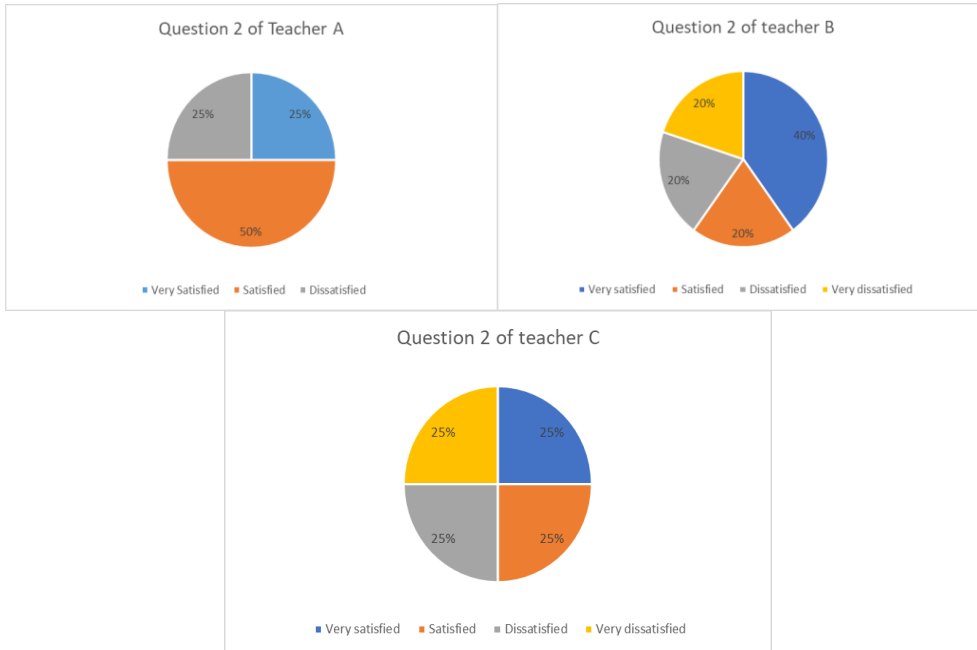


Figure 4. Visualization of scenario 2

We can draw the conclusion that, in comparison to teachers A and B, teacher C needs assistance in acquiring more pedagogical skills.

We use the following complex scenario to validate our assumption. We have completed our analysis of Teacher C on Class 3 of 5<sup>th</sup> level.

Table 4. Scenario 3 of the indicators Course and Class

| Indicator                                                     | Question                                                                       | Level of satisfaction             | Rate of the level of satisfaction |
|---------------------------------------------------------------|--------------------------------------------------------------------------------|-----------------------------------|-----------------------------------|
| Course AI<br>And then<br>Class 3 of the 5 <sup>th</sup> level | 2. Adopted pedagogy (method, justification, response to questions, and rhythm) | 3- Satisfied<br>4- Very satisfied | 60%                               |

The obtained results are the following:

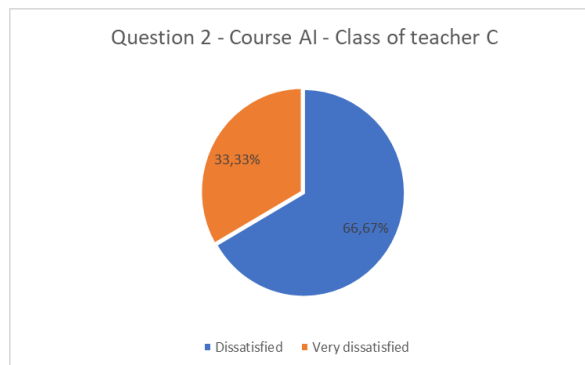


Figure 5. Visualization of scenario 3

Considering this, we can recommend that teacher C participate in the upcoming pedagogical training program. According to this finding, teachers A and B might not undergo the same training and might need to undergo other training programs by conducting other scenario analyses focusing on other aspects of the SET survey.

## **DISCUSSION**

The result we obtained was beneficial because, Teacher C being a former recruit was not necessarily concerned by specific pedagogical training. This fact was rectified by the results obtained using our training needs generation process for teaching improvement requiring need opportunities to develop and improve these competencies (Standard 10) in order to have the capacity to help students achieve a deeper working understanding of the relevant disciplinary fundamental (Standard 9). These results are then cross-referenced with the students' assessment's retrospection process established by teachers at the end of each evaluation session for the purpose of continuous improvement of student training programs through considering the program's effectiveness and efficiency in reaching its intended goals (Standard 12). Moreover, the obtained recommendations are insufficient to be used on their own for planning further trainings. They need to be combined with other strategies, including manager and teacher feedback.

## **CONCLUSION**

This article presents a mechanism for ToT generating needs based on the SET. The state of the art of earlier research on ToT and course evaluation served as the foundation for this methodology. By using this methodology on an actual case study, we were able to determine recommendations for future teacher trainings. We focused on the pedagogical aspect of AI modules, which is the subject of this case study. As a perspective, to have an exhaustive overview of the trainings needed we must focus on other elements like technical skills. It is also necessary to take a range of courses. As potential future research directions, we also propose evaluating the effectiveness of training interventions in teacher education. We will also focus on how these training programs will be implemented effectively.

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# PROJECT BASED ASSESSMENT IN THE ERA OF GENERATIVE AI- CHALLENGES AND OPPORTUNITIES

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## ABSTRACT

In recent years, generative Artificial Intelligence (GAI) has had a huge impact on education. Students can now prepare complex content with a very low effort, which puts in question the relevance of classic assessment methods. In this paper, we focus on the evaluation of a project-based learning course in a world where the student will benefit from GAI with its various forms of outputs. We explored the challenges of GAI on the project-based learning assessment, and we collected feedback from the course's teachers. Then, we proposed additional criteria in the evaluation grid relating to the use of GAI. We are convinced that we should take advantage of GAI while maintaining the academic integrity and ensuring development of student's critical skills. We concluded that the assessment grid should include 6 types of criteria which are: integrate AI-specific skills criteria, ethical consideration criteria, providing clear rubrics criteria, collaboration criteria, align with specification criteria, and quality of documentation criteria.

## KEYWORDS

Project based Learning, Assessment, Generative Artificial Intelligence, Standards: 8, 11

## INTRODUCTION

In the dynamic landscape of education, Problem and Project-Based Learning (PBL) has emerged as a transformative approach, especially in the realm of Computer Science Engineering (CSE) (Von Kotze & Cooper, 2000; McManus & Costello 2019). The Project-Based Learning (PjBL) pedagogical method has a rich history rooted in experiential learning, aiming to equip students with practical skills and a deeper understanding of theoretical concepts (Pucher & Lehner, 2011). As technology continues to evolve, the integration of PjBL in CSE curricula has become increasingly crucial.

Problem-Based Learning is not a recent phenomenon; its roots can be traced back to the progressive education movement in the second half of the 20th century (Barrows & Tamblyn, 1980). However, it gained prominence in the context of CSE as the field evolved from



theoretical concepts to practical applications. The shift from traditional lecture-based instruction to problem or project-based approaches marked a turning point in the educational paradigm. PBL engages students by presenting real-world problems and challenges, fostering critical thinking, collaboration, and problem-solving skills – essential attributes for success in the ever-evolving field of computer science (Chen & Yang, 2019).

In this paper, we propose to analyse the implications of the widespread use of GAI in the project assessment process. Focusing on CDIO Standard 11, our aim is to re-evaluate traditional assessment methodologies to reflect the emerging role of GAI in student work. Indeed, GAI not only provides automated tools; it also redefines the very contours of creativity, conceptual understanding, and problem-solving skills in the context of academic projects.

GAI, by enabling learners to produce complex content with relative ease, raises crucial questions about the relevance and fairness of the assessment process in educational projects. The aim of this study is to explore in depth the impact of GAI on the traditional project-based approach, focusing specifically on first-year computer engineering students. These students, accustomed to a dynamic learning environment, are particularly sensitive to the changes brought about by the increased power and accessibility of GAI.

The experimental approach, carried out in collaboration with committed educators, aims to explore the potential benefits of GAI as a complementary tool for improving student creativity and efficiency. However, beyond the expected benefits, our study also examines the complex challenges of the widespread use of GAI, particularly through the prism of CDIO standards 8 and 11. The preservation of academic integrity and the development of critical skills remain central concerns in this rapid move towards education infused with artificial intelligence (AI). With this in mind, our paper contributes to the current debate by highlighting the need to rethink assessment methods, aligning them with the new skills demanded by the era of GAI.

A background context will be presented in the first section of this paper. The following section will focus on an in-depth analysis of the integration of GAI tools in PjBL, highlighting opportunities, challenges, and a new assessment approach in the age of these technologies. The conclusion will point up our commitment to promoting an educational culture that combines academic integrity with the ethical use of generative technologies, while offering an assessment approach adapted to these rapid developments.

## **BACKGROUND**

GAI is a category of AI capable of creating new content and ideas, including conversations, stories, images, videos, and music as mentioned in Lim, et al. (2023). GAI demonstrates remarkable proficiency in generating unique content. This capability arises from the utilization of generative language models, which are founded on deep learning techniques. Several examples of GAI models are used for various applications, including GPT4, the language model behind ChatGPT introduced by Open AI, Google's BERT/BARD and Meta's Llama.

Various studies such as Lim, et al. (2023) and Mello, et al. (2023) have discussed the integration of GAI in education, highlighting its key role in shaping the future of learning. GAI in its various forms is impacting enormously on different aspects of education. In particular, it affected teaching and learning (Abunaseer, 2023; Farrelly & Baker, 2023). GAI models can be used to automatically create educational content with ongoing assistance for students by

providing additional explanations and personalized support. The personalization of learning enables providing each student with pedagogical content suited to his needs, skill level and learning style. GAI can also be used to automatically evaluate assignments, homework, and exams. This can speed up the assessment process and can provide rapid feedback. In fields such as medicine or engineering, GAI can be used to create simulations and Virtual Reality. This provides students with experiences that mimic realistic hands-on activities.

The increasing integration of GAI into educational environments is profoundly redefining the way students approach PjBL. The project-based approach, long considered a pillar of education, now finds itself at the intersection of innovation and the challenges posed by the emergence of GAI. In this changing context, where students navigate with ease through tools offering automated coding capabilities and the creation of sophisticated multimedia supports, the assessment of skills and knowledge acquired through educational projects is undergoing substantial transformations. While the benefits of GAI in education are many, it is crucial to adapt to this use of AI and to properly assess the new skills acquired by the student. Also, it is necessary to ensure that ethical challenges are considered and that these technologies are used fairly.

The success of PjBL lies not just on the final solution, but also in the entire process of inquiry, teamwork, and critical thinking it fosters. However, the rise of GAI poses a challenge to this dynamic approach, requiring us to address the obstacles that come with accurately and fairly evaluating student work. Let us examine some of the major difficulties in this ever-evolving landscape.

While AI tools are undoubtedly beneficial in streamlining tasks such as coding and media production, they can also hinder the development of crucial skills. Overdependence on automated outputs can weaken students' proficiency in coding and their ability to think critically and creatively when producing multimedia. This ultimately limits their capacity to grasp fundamental concepts and foster their own unique voices.

It is crucial to recognize the delicate balance between applying AI-generated outputs and fully comprehending the underlying principles. According to a study conducted by (Iskender, 2023), the accessibility of pre-written code and AI-generated visuals can hinder the development of critical problem-solving abilities, resulting in superficial understanding. Therefore, it is important for students to have a solid grasp of fundamental concepts to successfully adapt and troubleshoot, especially when the convenience of AI is not an option.

As we delve into the era of AI, maintaining academic integrity poses an exciting new challenge. The incorporation of AI outcomes in projects inevitably sparks debates surrounding originality and plagiarism. As noted in Gallent, et al. (2023), the distinction between student-produced work and AI-generated material can become blurred, hindering our ability to evaluate genuine learning and pinpoint instances of inadequate credits. To safeguard academic integrity, it is imperative that we establish unambiguous guidelines and encourage open dialogue on the responsible utilization of AI.

Further significant challenge we face is the potential impact on students' critical thinking and autonomy. In (Iskender, 2023), the author draws attention to the potential danger of students becoming overly dependent on AI-generated answers, consequently neglecting essential skills such as analysis, evaluation, and independent judgment. Therefore, it is imperative that we

prioritize educational strategies that promote critical thinking and encourage students to question, analyse, and draw their own conclusions, despite the availability of AI solutions.

Meeting these challenges demands thoughtful deliberation and proactive problem-solving. By embracing the potential pitfalls and embracing inventive strategies, we can guarantee that GAI will enhance, rather than impede, the growth of well-rounded, analytical-minded students in hands-on learning settings.

## **USE CASE**

In this section, we will dive deeper into the details of the course based on PjBL that was reviewed. We will examine the actual assessment schema and discuss the feedback of the tutors. This study will result in a new set of assessment criteria that embrace the wide use of GAI by our students.

### ***Course Description***

The C Project is a course designed for the first-year engineering students at Esprit. At the end of this project, students will be able to contribute, as a team, to the programming of a serious video game using the appropriate resources. The C project is an integrated project in which several courses contribute to its progress. (i) C programming for the implementation of the source code. (ii) The multimedia course for the preparation of the project's graphic resources. (iii) The English course where students develop the game's story.

This project follows a clear structure aligned with the different phases of the project life cycle, corresponding to conception, design, implementation and operation. The CDIO framework is an engineering education initiative that focuses on training students in fundamental engineering skills and real-world problem solving.

This course is evaluated based on formative and summative assessments. Formative assessment is an evaluation method applied during the learning process. This type of assessment ensures student motivation (Carney et al., 2022; Thangaraj, Ward, & O'Riordan, 2023), and enhances the quality of learning (Karaman, 2021; van der Steen, van Schilt-Mol, Van der Vleuten, & Joosten-ten Brinke, 2021). In this context, we apply the feedback process that aims to readjust behaviours and attitudes encouraging student learning.

The second type of evaluation used in the C Project is summative assessment, used twice during the programming session. The other evaluations are planned at the end of each integrated module session. Finally, a final assessment will be conducted on GD3 (Game Design Day), in line with the operational phase of the CDIO approach.

To assess students during programming sessions, a criteria-based grid is adopted to accurately assess the degree of skills achieved. This grid is based on specific assessment criteria, measurable indicators, a grading scale, and performance descriptors. The current project assessment grid incorporates various criteria for assessing skills, which are closely linked to the current training objectives. These criteria are carefully aligned with the current overall learning outcomes of the project.

## Results and analysis

The effectiveness of the old assessment grid when students are using GAI tools in their project was evaluated using a survey shared with 30 of the C Project instructors. We present in this section the results of the feedback survey designed to evaluate their opinion on the assessment method.

This study revealed the following findings:

- 100% of tutors confirm that all students use AI generative tools in their projects.
- ChatGPT is the most widely used tool.
- Students integrate AI tools at various stages of the project, including integration, design, project analysis and mainly the coding phase.
- The current evaluation grid disregards the use of GAI tools.
- The current evaluation grid needs to be revised.

As stated in the form submitted to collect feedback from the C Project teachers, the traditional assessment grid does not allow to assess all the skills acquired by the student. It may fall short in evaluating the skills and competencies acquired through using GAI in hands-on projects. The current grid needs substantial transformations and must include criteria that evaluate creativity, conceptual understanding, problem-solving skills in the context of academic projects, and ethical use of generative technologies. Based on these results, we decided to propose a new assessment approach integrating the use of GAI tools. We will describe our proposed solution in the next section.

## Proposed update

When reviewing the current project criteria, we realized that the current criteria are of three types (i) collaboration criteria, (ii) align with specification criteria and (iii) quality of documentation criteria. We present in the table 1 the detailed criteria of the old grid.

Table1: Old criteria of the assessment grid

| Criteria                                                     | Details                                                                                                                                                                                                  |
|--------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Propose the game story                                       | - The students should be able to define all elements of a short story, and appropriately write the story and plot of their game.                                                                         |
| Design the required multimedia resources                     | - Students should be able to construct a creative setting for their video game.<br>- Students should be able to develop a description of their characters' physical appearance and actions in the story. |
| Design a game controller                                     | - The student must simulate the electronic components and make the serial communication.                                                                                                                 |
| Group game modules                                           | - The student must integrate all his tasks while respecting the game's design.                                                                                                                           |
| Act / organize as a team in a cooperative and productive way | - Student must be collaborative with all their peers, help their peers, be independent and always take the initiative.                                                                                   |

|                                       |                                                                                                                         |
|---------------------------------------|-------------------------------------------------------------------------------------------------------------------------|
| Defend the project in front of a jury | - The student must present the game in English. He must be presentable, wear his badge, and be able to convince a jury. |
|---------------------------------------|-------------------------------------------------------------------------------------------------------------------------|

Since these criteria (table 1) do not consider the use of GAI tools, we recommend therefore to add criteria relating to this context. We propose these criteria mentioned in table 2.

Table2: Proposed additional criteria to be integrated into the current grid

| Criteria                     | Details                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Integrate AI-specific skills | <ul style="list-style-type: none"> <li>- The student integrated AI into his project.</li> <li>- The student integrated various AI tools.</li> <li>- Student's ability to overcome technical challenges related to AI.</li> <li>- Innovation Degree in the use of AI.</li> <li>-The student adapted AI-generated code to fit the project context.</li> <li>- Coherence with project and course objectives.</li> <li>- Quality of results obtained through AI integration.</li> </ul> |
| Ethical consideration        | <ul style="list-style-type: none"> <li>- Transparency: the student presents an AI with a clear making decision process: algorithm, architecture, parameters, etc.</li> <li>- Explainability: the student understands and can explain how the AI works: algorithm, architecture, parameters, etc.</li> <li>- Informed Consent: Emphasizing the importance of obtaining consent when using AI tools.</li> </ul>                                                                       |
| Providing clear code         | The student presents a commented and well-structured code with clear rubrics according to the specifications.                                                                                                                                                                                                                                                                                                                                                                       |

## DISCUSSION AND EXPLORATION

Before proposing an evaluation grid, teachers first need to understand the role of AI in the project. Basically, they need to answer three questions: (i) Which parts of the project can be achieved with an AI? (ii) How can we update project inputs and outputs? (iii) What AI tools can be used to achieve the tasks?

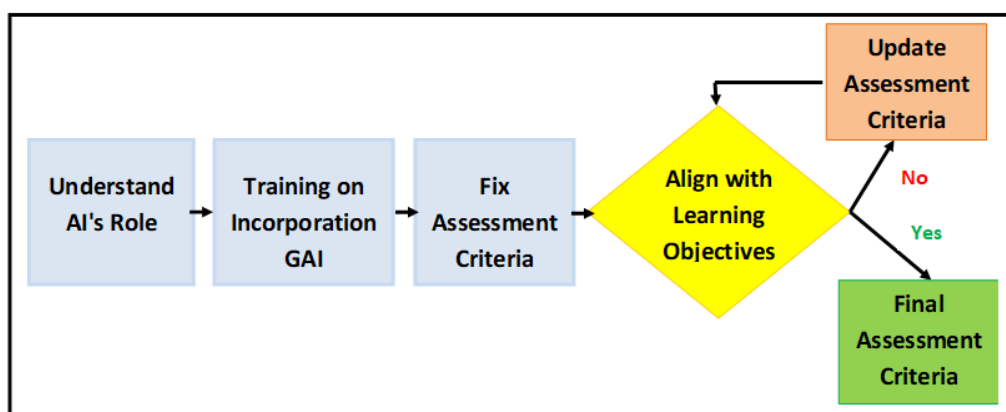


Figure 1. Producing the evaluation grid steps

The next step is to quantify the effort required to integrate AI outputs into the project. Once this is complete, initial assessment criteria will be proposed. The alignment of these criteria with the learning objectives previously defined must be confirmed. As long as this alignment is not confirmed, an adjustment must be made. The figure 1 demonstrates the steps we propose in our approach to prepare the final assessment criteria.

To foster deeper learning, we recommend incorporating the following criteria into the PjBL assessment grid, as illustrated in figure 2:

- Integrate AI-specific skills criteria: These are the most relevant criteria in the assessment grid. They aim to assess how students apply AI techniques to solve complex problems and consider their ability to choose appropriate algorithms and models for specific tasks. They may also include criteria to assess how students evaluate the performance of their AI models and consider their ability to interpret and communicate results effectively. These criteria may include algorithm design, data pre-processing and model evaluation.
- Ethical consideration criteria: These are crucial to ensure responsible and respectful use of technology. Students should make sure their projects comply with the regulations and ethical standards in force in their field. We should define Ethical Principles which may include transparency, accountability, non-discrimination, privacy, and security, and assess Potential Ethical Risks which may include algorithmic biases, privacy issues, or unintended social consequences. We must also develop measurable indicators to assess compliance with ethical principles. For example, how will you measure the transparency of your model or the way it avoids discrimination?
- Providing clear rubrics criteria: These criteria need the definition of clear expectations for the different levels of achievement and the development of clear and transparent sections for each requirement.
- Collaboration criteria: These include criteria that assess teamwork and communication skills and consider the role of each team member in the development process.
- Align with specification criteria: The deliverable in question must meet the requirements specified in the initial specifications. That means no additional or missing functionality.
- Quality of documentation criteria: These criteria assess students' ability to effectively communicate their solutions, including code comments and project reports.

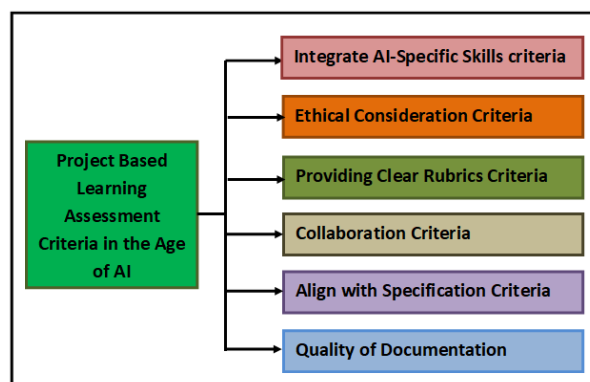


Figure 2. Proposed criteria for the project-based learning assessment in the era of GAI

## **FUTURE DEVELOPMENTS**

GAI is transforming PjBL assessment, going beyond just rating final projects to uncovering the hidden layers of student learning. Consider AI evaluating, student interactions with code snippets, design recommendations, or multimedia elements to show their problem-solving tactics, decision-making processes, and areas of difficulties. This data enables formative assessments, individualized feedback, and the discovery of learning gaps, all while relieving instructors from the chore of grading through plagiarism detection, basic code checks, and automated reporting. This saved time allows educators to facilitate in-depth conferences, provide targeted feedback, and guide group collaborations, resulting in deeper student involvement.

GAI takes evaluation a step further by creating personalized feedback reports, recommending relevant learning resources, and even tailoring the program to individual needs. Students who have gained such insights can use AI-powered self-assessment tools to track their progress, set goals, and celebrate their growth journeys.

GAI overcomes geographical and cultural gaps by facilitating global collaboration among students through translation tools, virtual reality environments, and collaborative brainstorming platforms. Within PjBL experiences, this promotes intercultural awareness, communication skill development, and a global perspective.

In addition, GAI assessment shifts its focus from evaluating just the end result to valuing the complete learning path. Along with the final project outcomes, process-oriented rubrics, portfolio building, and self-reflection prompts recognize effort, growth, and individual learning journeys.

Finally, GAI reconsiders PjBL assessment, resulting in a dynamic, efficient, and customized system that fosters student growth, supports learning, and honors the genuine spirit of PjBL.

## **CONCLUSION**

Nowadays, the great challenge faced by education is to meet the needs of learners in an ever-changing world where digital transformation and AI increasingly dominate society and the job market. In order to preserve the ethical principles and integrity of learning, while taking advantage of the opportunities offered by technological advances, it is imperative to thoughtfully review educational practices. In this light, teaching should consider a revision of conventional teaching and assessment methods, adopting proactive approaches that incorporate technological innovations. In this context, we have discussed in our research work (Neji, Boughattas, & Ziadi, 2023), the importance of GAI tools in education. In fact, we integrated ChatGPT as a teaching support tool for learning, while highlighting the advantages and challenges encountered.

Based on the adoption of these new technologies, and following expertise feedback from the project's tutors' team, we recognized the necessity to review the actual assessment method. To this end, we have proposed a new assessment approach which considers the integration of GAI tools in PjBL. To achieve this, an update of the criteria-based grid is deemed necessary by introducing additional criteria to evaluate the following points: the integration of AI-specific skills, the ethical consideration and the quality of provided code.

In conclusion, the use of GAI is incontestable. Careful exploitation and adaptive adjustment offer significant advantages. AI, when properly applied, not only promotes positive results and teaching motivation, but also has the potential to raise students' level of competence and knowledge to the synthesis stage in Bloom's Taxonomy. Acquiring this level will enable the student to understand in depth, apply the knowledge acquired in a variety of contexts and create innovative solutions in response to changing needs.

As perspectives, we propose to focus on current pedagogical approaches that need to be adjusted to accommodate the rapid advances in AI. This will better prepare students for the realities of AI. We are also looking at integrating AI tools into the assessment process to offer specific guidance to students based on individual performance.

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# A DATA-DRIVEN APPROACH TO FLIPPED LEARNING FOR DIFFERENTIATED INSTRUCTION IN ELECTRONIC ENGINEERING

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## **ABSTRACT**

This paper documents an evaluation of a project that aimed to use a technology platform in a flipped learning format that generates student performance data to provide a differentiated learning environment. This project was focused on enhancing key aspects of the student learning experience, especially in relation to CDIO Standards 8: Active Learning and 11: Learning Assessment. The technology employed the Brightspace Learning Management System, especially the learning analytics features, to extract, collate, and present key performance data on online assessment in preparation for focused feedback and differentiated instructional activities in the face-to-face sessions. The scope of the implementation at the School of Electrical & Electronic Engineering (EEE) at Singapore Polytechnic (SP) involved 36 classes, 20 lecturers and 648 students. The methodology followed a broad Action Research approach that sought to understand how the initiative impacted the students learning experience, as well as how teaching faculty dealt with the challenges of the instructional approaches employed. The evaluation findings showed positive results on the use of the selected active learning methods (e.g., challenging questions, peer instruction, and differentiated learning activities). The design and use of the active learning methods reflected the integration of subject content with key critical thinking skills (e.g., analysis, evaluation) about the concepts the students were learning and their application in real work contexts. The importance of providing focused and timely feedback for enhancing student understanding was also supported in the data obtained. Future research will seek to incorporate emerging generative Artificial Intelligence (AI) tools that can further enhance SP's goal towards providing a holistic education underpinned by the CDIO framework.

**KEYWORDS:** Active learning, Differentiated instruction, EdTech, Standards 8, 11.

## INTRODUCTION AND CONTEXT

It was not that long ago that Petty (2009) argued that teaching was ready to: ...embark on a revolution, and like medicine, abandon both custom and practice and fashions and fads, to become evidence-based (cover page).

Certainly, we are rapidly increasing our knowledge relating to how humans learn, what teaching methods and practices work best, and why. The significant research on learning is well documented in the literature (e.g., Bransford, 1999; Marzano, 2007; Hattie, 2009, Hattie & Yates, 2014, Sale 2020). Collectively, the research evidence increasingly framed as Evidence-Based Teaching (EBT) is now providing us with a heightened pedagogic understanding of the various facets of highly effective teaching. In turn, this should lead to enhanced attainment and engagement opportunities for a wider range of student groups.

Furthermore, in the past decade or so, and especially resulting from the Covid-19 epidemic, technology-based learning formats such as online learning, blended learning, and flipped classroom learning have become increasingly popular as preferred delivered modes in many educational and training contexts. Ongoing research evidence suggests that blended learning formats are not only more efficient and flexible but also more effective than either face-to-face or fully online learning (e.g., Means, Toyama, Murphy, Bakia, & Jones, 2010; Abeysekera & Dawson, 2015; Shao & Liu, 2021).

More recently, *Learning Analytics* (LA) in learning management systems can collect, analyse, and present students' performance data in highly visual ways to enable both rapid and focused feedback and guide instructional interventions during face-to-face tutorial classes (e.g., Mian, Khalid, Qun & Ismail, 2022).

Moving forward with continually improving student learning, and with the progress made in EduTech tools, SP introduces the DEFL framework to bring together the use of flipped learning, EBT, ALeRT and learning analytics. SP has comprehensively employed flipped classroom learning (e.g., Sale, Cheah, & Wan, 2017). The acronym ALeRT stands for "Assessing Learning Regularly for Timely Support". Its implementation was documented in other papers (e.g., Wan & Chong, 2021; Wan et al., 2023). With this, SP hopes to provide more differentiated instructional activities through the ability to do real time assessment and provide timely and focused feedback to its students.

DEFL is essentially an EBT and EdTech blended intervention. In summary, it provides an integrated pedagogic approach that employs specific instructional strategies with technology affordances to enhance key aspects of the student learning experience. In the context of CDIO Standards, it focuses on 8: Active Learning and 11: Learning Assessment, but it also impacts other standards, as it involves considerations of learning outcomes, integration, faculty development, and program evaluation.

The summary of the DEFL Model is depicted in Figure 1 below. The key instruction process and features include:

- a) Instruction on key subject content knowledge aligned to selected learning outcomes are delivered through asynchronous lectures.
- b) Diagnostic testing of key concept knowledge. This assessment method is intentionally chosen to comprehensively evaluate both students' learning and identify potential gaps in understanding key concepts. This strategic selection aligns seamlessly with CDIO Standard



- c) 11: Learning Assessment, emphasizing the importance of aligning assessment methods with learning outcomes.
- d) Student differentiation based on performance in the pre-class tests, and allocation of students to activities for the face-to-face sessions.
- e) A variety of active learning strategies such as group discussions, peer learning and two-way feedback are employed in the face-to-face sessions customized to students' needs based on the assessment data. CDIO Standard 8: Active Learning is deliberately and seamlessly implemented in face-to-face sessions.
- f) Formative assessment (e.g., quiz) and feedback (CDIO Standard 11: Learning Assessment) are conducted after class to check the effectiveness of face-to-face sessions and the need for any follow-up.
- g) Use Learning Analytics for ongoing insight into students' performance to guide future instructional activities.

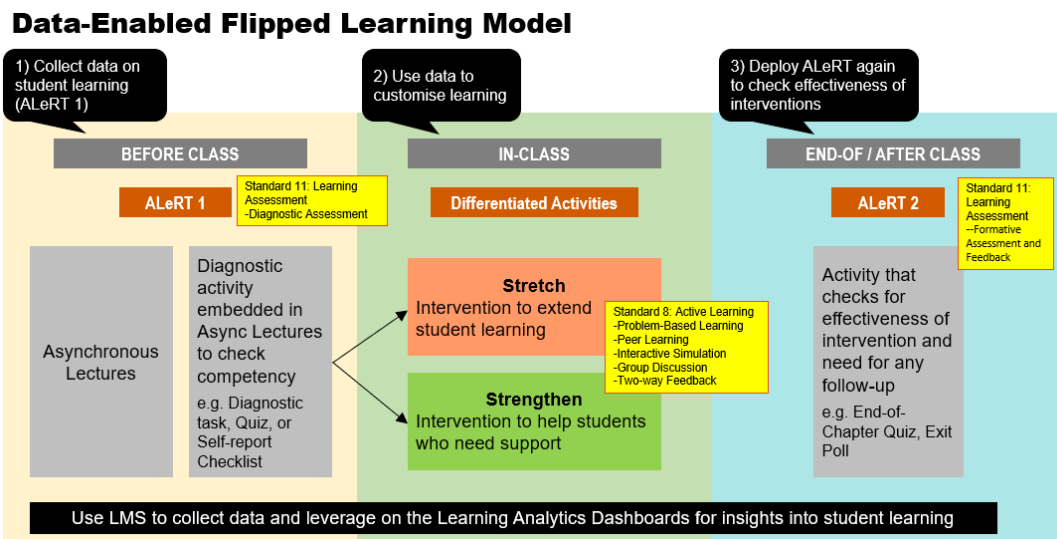


Figure 1. Data-Enabled Flipped Learning (DEFL) Model

The design and delivery of the DEFL is consistent with the application of the CDIO Framework, which is shown schematically in Figure 2, by making a simplified representation of DEFL shown in Figure 1 (Cheah, 2024):

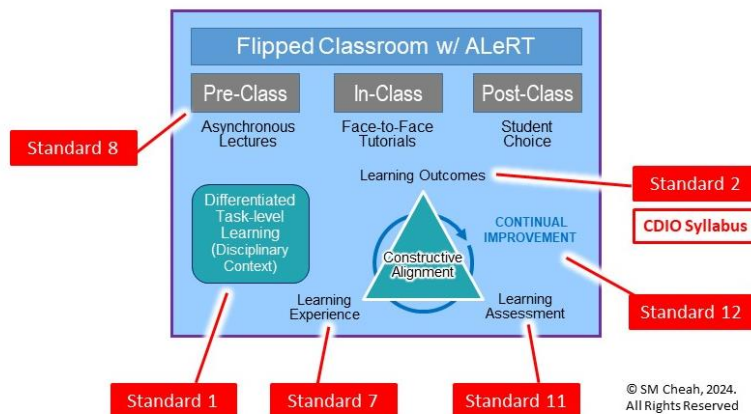


Figure 2. How CDIO Framework supports the application of DEFL (Cheah, 2024)

## RESEARCH OBJECTIVES

The broad research objectives focused on:

- How useful did students find the instructional format and approach employed (e.g., quizzes, learning activities, challenging questions, peer teaching) to support their learning (e.g., clarifying expectations, providing timely and supportive feedback, creating interest and challenge)?
- How did teaching faculty experience the initiative in terms of their professional role (e.g., able to identify student-specific learning gaps, gain better insights into student understanding to provide effective two-way feedback, and design and facilitate more differentiated and personalized instruction)?

## METHODOLOGY

The present initiative involved 36 classes of the Digital Electronics module (ET1004), in which 20 teaching faculty and 648 EEE students were involved in AY2022/23 Semester 2. The methodology was designed to capture specific aspects of the learning experience of both students and teaching faculty during the project intervention duration. The methodology involved collecting quantitative and qualitative data through a questionnaire, comprising fixed and open response items, tailored to the research goal and key questions. The questionnaire items were provided by the polytechnic's educational department for staff to evaluate the effectiveness of DEFL. The full questionnaire items are contained in Appendix A & B. In addition, separate focus group interviews with five staff were also conducted.

This paper followed the broad aims and process of action research (AR), which primarily seeks to understand better and improve practice – in this case, how a large-scale pedagogic intervention could enhance student learning for a wider student cohort. Quantitative analysis was used to collate student and staff responses to the fixed response items and facilitate the analysis and interpretation of this data. For the qualitative data, derived from the open-response items, a broad thematic coding approach was employed to identify, analyse, and interpret common patterns in the data (e.g., repeated/similar meaning responses) to frame main categories.

## RESULTS & ANALYSIS

### ***The Student Learning Experience***

The summary data from the fixed response items in the student questionnaire are presented below in Figure 3. A total of 203 out of 648 students participated in the survey, resulting in a response rate of 31%.

Overall, the data suggest that students were positive about the various components of the initiative. The provision of variation in the learning activities, challenging goals, timely and helpful feedback, and clear expectations for learning are all congruent with research on what teaching methods work best. To illustrate, Feedback has an Effect Size of 0.73 and Challenging Goals, of 0.57 (Hattie, 2009). The relatively lower positive response for 'The learning activities assigned gave me confidence in my learning', is perhaps more difficult for students to answer as assessing one's confidence may be less easy than the other constructs provided.

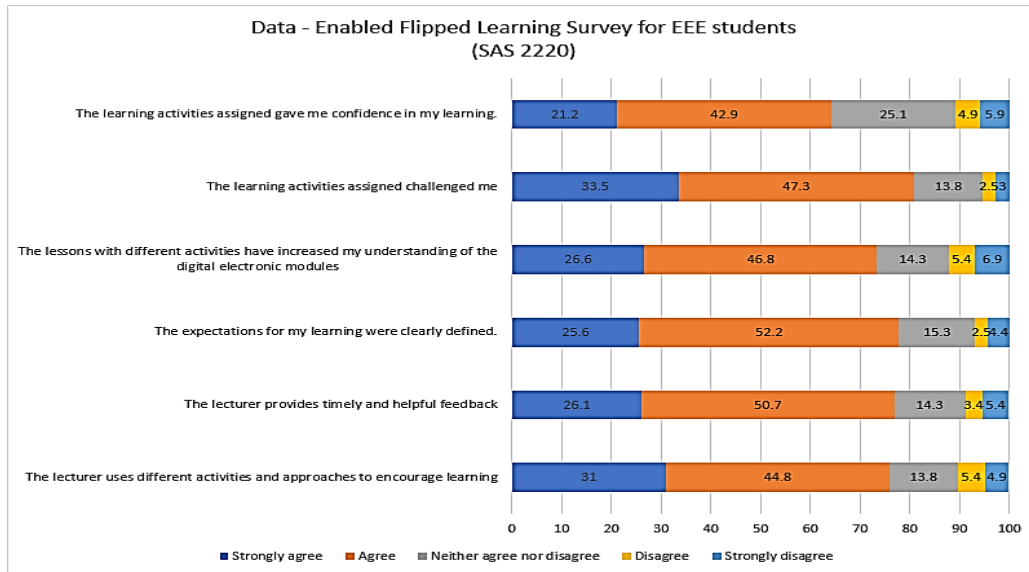


Figure 3. Data-Enabled Flipped Learning Survey for EEE Students

The data from the open response items focused on identifying:

- The 'muddiest' points of the module (topics requiring more clarification) (Q.7)
- Personal experience from doing this module (Q.8)
- What learning activities are most liked and why (Q.9)?

For Q.7, the only most notable area that the students found the 'muddiest' related to the understanding of Multiplexers and Demultiplexers; with 22 references to these concepts and their application. Tables 1 & 2 summarize the responses for Questions 8 & 9.

Table 1. Q.8 Personal experience from doing this module

| Category                         | Number of Responses |
|----------------------------------|---------------------|
| Positive (Good, Enriching, Fun)  | 45                  |
| Organized/Clear Explanation/Pace | 10                  |
| Challenging tasks                | 4                   |
| Resources on Brightspace         | 3                   |

Table 2. Q.9 The learning activities most liked and why

| Category              | Number of Responses |
|-----------------------|---------------------|
| Challenging Questions | 39                  |
| Peer Teaching         | 38                  |
| Class Presentations   | 8                   |
| Pre-class Quizzes     | 4                   |

A notable inference from the data is that the strategic blending of effective methods is important, as they seem to have a synergistic impact. This is consistent with the work of Hattie (2009) who used the analogy of a 'Russian Doll' to describe the process of combining several effective methods into the overall instructional strategy.

However, there were six responses of not liking the module, and one student specifically saw the peer teaching as not useful, as it led to some students doing all the work, while others were able to benefit without making a personal effort. Eight negative comments were recorded relating to the exit poll, captured by one student respondent:

“I don't think exit polls are useful since most of the time, I do it for the sake of completing it. Any questions I have I would ask in class or otherwise would be cleared up when going through pre-class quizzes or tutorial sessions.”

There was also variation in the perception of the instructional effectiveness of teaching faculties – many were very positive, while some were quite negative.

“My learning experience for this module is very fun and curious because the lecturer every time come out with new idea to teach us to understand better”

“Module was interesting, but the lecturer was not up to standard. I had to chase other lecturers for help.”

In summary, the findings on student learning experience showed positive results on the use of the selected active learning methods (e.g., challenging questions, peer teaching, and differentiated learning activities). The findings were consistent with Standard 8: Active learning, which emphasizes engaging students in thinking about the concepts they were learning and their application in real work contexts. The importance of providing both focused and timely feedback for enhancing student understanding were supported in the data obtained, consistent with CDIO Standard 11: Learning Assessment.

### The Staff Learning Experience

The summary data from the fixed response items in the staff questionnaire are presented below in Figure 4. A total of 12 out of 20 staff participated in the survey, resulting in a response rate of 60%.

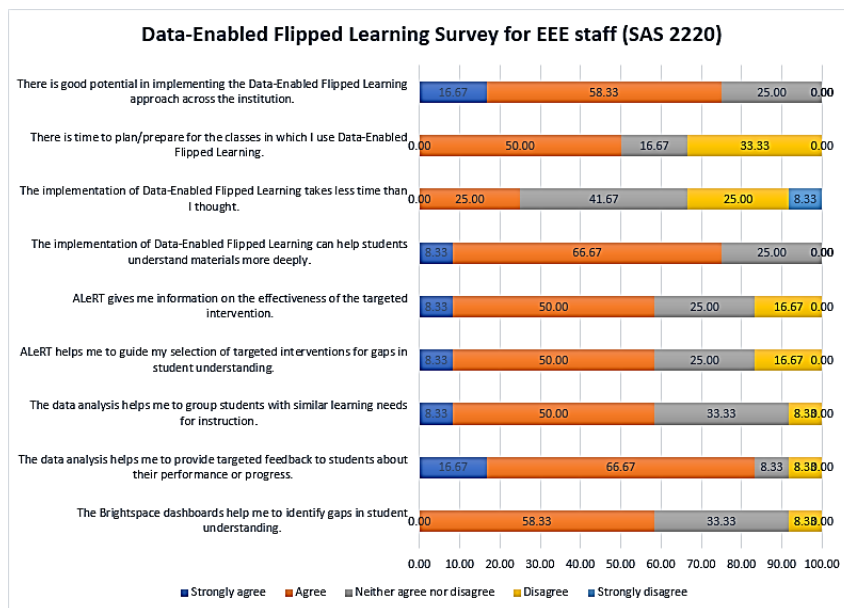


Figure 4. Data-Enabled Flipped Learning Survey for EEE Staff



The staff's response on the potential learning benefits of implementing the DEFL approach across SP can be described as positive, with 75% either strongly agreeing or agreeing. There is no response for disagreeing or strongly disagreeing. The highly favourable response for helping students to understand more deeply and provide targeted feedback (75% and 83.34%, respectively) seems to align with the student perceptions in these areas.

The main areas of disagreement or neither agree nor disagree relate to the time needed to plan instructions and implement the initiative (50% and 75%, respectively); notably, only 25% agree that the implementation takes less time than previously thought. The data from the open response items focused on identifying:

- The advantages and disadvantages of using the Data-Enabled Flipped Learning Approach (Q's 7 & 8 respectively)
- Their experiences in using the three learning designs, and suggestions for future improvement (Q.9)
- The support needed to adopt the approach (Q.10).

Tables 3 & 4 summarize the responses:

Table 3. Q.7: Advantages of using the DEFL Approach

| Category                         | Number of Responses |
|----------------------------------|---------------------|
| Understanding students' learning | 4                   |
| Self-Directed Learning           | 2                   |
| Evaluate Instruction             | 1                   |

Table 4. Q.8: Disadvantages of using the DEFL Approach

| Category                                   | Number of Responses |
|--------------------------------------------|---------------------|
| Time constraints                           | 2                   |
| Limitation of Data Produced by Brightspace | 1                   |
| Too few pre-class quizzes                  | 1                   |

The most notable advantage was the ability to gain more precise insight into how students were learning the topics. This enabled them to better identify what has been learned, understand specific knowledge gaps, and provide further instructional direction. Students being given the opportunity to do work independently and develop self-directed learning skills was also seen as a positive outcome.

The main disadvantage related to the additional time needed to prepare instructional material. This was seen as time consuming and to use the words of one staff respondent, "Progress of teaching is slower". One respondent also highlighted the "need for statistics and data presentation for each class, not just the whole cohort which is the current situation in Brightspace. Without relevant data, it is meaningless to talk about the advantages of DEFL". In terms of support needed to adopt DEFL, time was seen as the main concern, and two respondents specifically noted the need for more tutorial hours. Three other responses may be significant in terms of future planning:

"Flipped classroom learning takes too much time from teachers who may need more time to help weaker students."

“As we are doing self-directed learning, perhaps over time, the system can be built up in such a way that at the end of the pre-class quiz, the students with questions answered wrongly can be directed to the material that explains the concept right away.”

“I support it if the data provided is directly relevant and can be used immediately without the need to spend too much time analysing the data further.”

The focus group, involving five staff, reinforced the findings from the questionnaire. The capability to enhance student learning was noted, especially in relation to identifying students who needed support, and the variety of activities that seemed to engage most students. One respondent made the pertinent point: “I like the fact that we have deliberately designed active learning in the class.”

On the negative front, concerns about time and the perceived limitations of the present data analysis (as identified previously) were reiterated. Concerning time, one staff wrote:

“If I have to do all these things, I easily use up 25% of my 2 hours in class. 1/4 of the time is spent on all these things in the class, which is not productive.”

On the data analysis issue, staff wrote:

“...if you are not able to see the information by the class, then it is not useful for the DEFL. It's only useful for maybe the course review or coordinator.”

“I feel that there needs to be a way to make sure that the data being collected is accurate because even if you have data, if the data is not accurate, it's pointless.”

In summary, the findings on staff's experience were highly positive on DEFL's capability to enhance student learning and identify students who needed support. The main concerns on time and data analysis were noted. Specifically, to streamline and enhance the data analysis process for the new semester, the educational department has developed the DEFL dashboard, and the staff can filter the quiz data by class.

## **IMPLICATIONS FOR PRACTICE & RECOMMENDATIONS**

As the student and staff data is consistently positive about the initiative overall, as identified in the questionnaire and supported in the qualitative feedback, the implications now focus on how best to further enhance both the range of active learning methods employed, and support staff development in their capability to utilize and integrate them consistently in their practices.

To support staff development, the main recommendation is to develop what Hargreaves and Fullan (2012) refer to as ‘Professional Capital’ - that is to achieve institutional capability in applying DEFL effectively and efficiently across all courses in SP. As SP has a well-established CDIO framework, and a strong evidence-based pedagogy, DEFL is potentially highly scalable. This can be achieved as the format can be modelled and customized to different courses, and through the Poly wide network of academic leaders and strong learning community spirit. At the level of professional development, staff can be encouraged to conduct further action research on implementing the key active learning and feedback methods employed. For example, the use of questioning, peer instruction, and setting challenging goals are all well

validated active learning methods in terms of enhancing learning outcomes (e.g., Hattie, 2009). This will further support wider CDIO progression, especially Standard 10: Enhancement of Faculty Teaching Competence, as it will require SP staff to ensure they have high levels of competence for creating, delivering, and improving these areas of practice in their courses.

## **FUTURE DIRECTIONS**

Future research will seek to employ statistical tests on pre and post data to establish the variation in outcomes generated, enhance aspects of the questionnaire design, and extend the implementation of AI technologies that positively impact the learning process. For example, this semester, we have employed a customized AI chatbot driven by generative AI that provides content to address the specific needs of individual students. It also enables ongoing precise prompt adjustments to make the learning process more effective and engaging for them.

## **CONCLUSION**

The research has contributed to a better understanding of how both students and faculty have experienced this intervention, which were the key objectives. It has demonstrated that from a well-established CDIO curriculum framework, we can now both further enhance students' learning experiences and faculty capability in providing quality and differentiation through emerging technologies.

## **ACKNOWLEDGEMENT**

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## APPENDIX A

### DEFL Survey Questions for EEE Students

1. The lecturer uses different activities and approaches to encourage learning.
2. The lecturer provides timely and helpful feedback.
3. The expectations for my learning were clearly defined.
4. The lessons with different activities have increased my understanding of the digital electronic modules.
5. The learning activities assigned challenged me.
6. The learning activities assigned gave me confidence in my learning.
7. What muddiest point(s) about the module topics that you still need clarification on after going through the assigned learning activities.
8. Please share with us your learning experience for this module.
9. Which learning activities (e.g., challenging questions, peer teaching etc..) do you like the best and why?

## APPENDIX B

### DEFL Survey Questions for EEE Teaching Staff

1. Your perception of the data provided by the Brightspace visuals.
  - a. The Brightspace dashboards help me to identify gaps in student understanding.
2. Your perception of data analysis for flipped learning.
  - a. The data analysis helps me to provide targeted feedback to students about their performance or progress.
  - b. The data analysis helps me to group students with similar learning needs for instruction.
3. Your perception of teaching strategies resulting from ALeRT.
  - a. ALeRT helps me to guide my selected of targeted interventions for gaps in student understanding.
  - b. ALeRT gives me information on the effectiveness of the targeted intervention.
4. Your perception of beliefs
  - a. The implementation of DEFL can help students understand materials more deeply.
5. Your perception of time
  - a. The implementation of DEFL takes less time than I thought.
  - b. There is time to plan/prepare for the classes in which I use DEFL.
6. Your perception of potential
  - a. There is good potential in implementing the DEFL approach across the institution.
7. What are the advantages of using the DEFL approach?
8. What are the disadvantages of using the DEFL approach?
9. How do you feel about the three learning designs? What changes would you make to make the lessons better?
10. What support do you need to adopt the DEFL approach?

# **INSTITUTIONAL TEAMWORK SKILLS DEVELOPMENT AND MEASUREMENT AT SINGAPORE POLYTECHNIC**

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## **ABSTRACT**

Teamwork or collaboration is recognised by many governments and international agencies as an essential life skill and competency in the workplace. Employers almost always rank teamwork among the top competencies expected of college graduates. In Singapore, SkillsFuture Singapore (a government agency driving skills equipping at the national level) identifies it as a core skill, and it is reflected in the MOE (Ministry of Education) framework for 21st Century Competences. At the Singapore Polytechnic (SP), collaboration skill is one of our graduate attributes. To hone collaboration skill, many educational institutions incorporate collaborative exercises and teamwork projects as learning experiences for students. While such learning activities increase the opportunities for team interaction, putting students in a group does not necessarily lead to the development of teamwork skills. To effectively develop teamwork skill, teamwork learning activities need to be carefully designed and integrated throughout the course. Empirical studies have shown that teamwork skills improved after students were systematically given explicit teamwork instruction, opportunities to practise teamwork skills and formative feedback on their teamwork skills across their curriculum. This paper describes how teamwork skills development and measurement is holistically and systematically supported and developed in SP. The journey starts with an educational innovation project by an academic staff which led to a small-scale pilot project in AY20/21 before scaling to an institution-wide roll-out to all students joining SP in the AY23/24. The goal of this teamwork project is twofold: firstly, to develop teamwork skills systematically over a three-year diploma course, and secondly, to obtain psychometrically reliable and valid teamwork scores to inform the development of teamwork skills in SP students, leading to the award of a Teamwork Metric at graduation. The metric enables the quantification and evaluation of collaborative performance, providing a critical foundation for assessing and improving teamwork skills within an educational setting.

## **KEYWORDS**

Teamwork, Interpersonal Skill Development, Interpersonal Skill Assessment, Peer Feedback, Standards: 2, 3, 11

## INTRODUCTION

Numerous innovative approaches to cultivating teamwork skills have emerged, with dedicated efforts focused on class activities or modules (Ling & Tao, 2021; Ng & Tan, 2021). While individual learning activities within classes or modules are valuable, it is crucial to recognize that mastering teamwork skills goes beyond a single module. Research suggests that explicit instructions, practice opportunities and formative feedback enhance teamwork skills. Zou and Ko (2012) showed that teamwork skills improved after the Hong Kong University of Science and Technology students were systematically given explicit teamwork instructions, opportunities to practise and formative feedback across their three-year curriculum. Other researchers echo the usefulness of multiple learning experiences and longitudinal measurements over the program rather than within single modules (Siciliano, 1999; Donia, Mach, O'Neill, & Brutus, 2022; Farland & Beck, 2019). This adds another layer of challenge to the academic administration system as it must track teamwork skills development across different modules and course-level aggregated teamwork skill measurement. This challenge is compounded when the teamwork award is meant for the entire population of students across the whole institution. To address the challenge, the academic administration system must, at the very least, be able to track the teamwork skills development across different modules to produce a course-level aggregated teamwork skills measurement.

## LITERATURE REVIEW

While a substantial body of implementation studies addresses the scaling of educational innovations (Wyss & Robinson, 2021; List, Suskind, & Supplee, 2021; Robinson, Wyss, & Hannahan, 2021), there is a paucity of research specifically targeting the scale-up implementation of teamwork skills development at the institutional level. Despite the importance of scaling as observed by Mickelsson, Kronlid, & Lotz-Sisitka (2019), they noted that views on scaling educational activities were often vague. Others suggested that the concept of scaling is under-researched, particularly in education and learning fields (Mickelsson, 2018) and highlighted the lack of theoretical frameworks underpinning it (Harwell, 2012; Fischer, et al., 2015).

SP's institutional implementation of the development and measurement of teamwork skills in all courses adds to the knowledge of how to scale, especially in teamwork skills development. The implementation process will be elaborated using the innovation-learning-scaling up process developed by Linn, Hartmann, Kharas, Kohl and Massler, 2010, as illustrated in Figure 1. In the beginning, the impact of our new educational innovation experiences was limited and slow. To achieve greater impact, the project had to be scaled up. Through capacity development and learning from the pilot project, an institutional scale-up plan was developed and implemented.

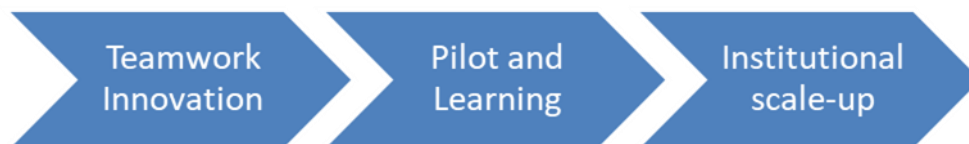


Figure 1. From innovation to pilot to institutional scale-up



## **SINGAPORE POLYTECHNIC (SP) INSTITUTIONAL CONTEXT**

In this paper, teamwork is viewed as an individual skills-set that students deploy, to contribute to the success of groups or teams they are a part of (Hughes & Jones, 2011). Collaboration is an SP graduate attribute. The other five are: competency & versatility; creativity, innovation & enterprise; ethics & responsible citizenry; self-directedness & personal effectiveness; and global mind-set. These attributes lie at the heart of our SP Education Model. In this paper, teamwork and collaboration are used interchangeably.

## **TEAMWORK EDUCATIONAL INNOVATION PROJECT**

The seed for the Teamwork Project (TWP) was planted by an academic staff, whose interactions with two visiting academics kick-started his personal learning journey and practices in fostering communication and collaboration among students in his course. He experimented with forming diverse teams, held students accountable for their own growth in teamwork skills through self and peer assessment and deployed team-based learning pedagogy in his classes. When he started, he used Excel spreadsheets to manually compile his students' self and peer assessment feedback. The institution's timely acquisition of Learning Activity Management System (LAMS) allowed the staff to leverage on the system to automate the rollout of the self and peer assessment (SPA) teamwork survey to fellow colleagues teaching the same course, online. The SPA survey comprises the five quantitative and two qualitative CATME (Comprehensive Assessment of Team Member Effectiveness) questions. The CATME instrument was developed by Ohland, et al., (2012) for use in colleges to measure teamwork skills and is derived from literature on teamwork effectiveness. The five quantitative questions in this self and peer evaluation instrument are: (1) Contributing to the team's work, (2) Interacting with teammates, (3) Keeping the team on track, (4) Expecting quality, and (5) Having relevant knowledge, skills and abilities (KSAs).

The staff began sharing his learning experiences informally, at various institutional platforms such as Excellence in Education & Teaching Convention (EETC) and the Pedagogy Committee. This encouraged colleagues in other schools to experiment with the SPA teamwork measure in their own classes. In 2017, the SPA teamwork measure came to the attention of senior management at SP when the staff had the opportunity to share on "Team-based Learning Made Easy" with visitors to the institution. The accompanying delegation from SP included the PCEO (Principal & Chief Executive Officer). Interest was expressed in tracking students' teamwork skills development over the three years at SP.

## **PILOT AND LEARNING**

At the request of SP's PCEO, a modest institutional pilot of the SPA teamwork measure to one three-year diploma course in every school (the "one-school-one-course" pilot) in the institution began in AY 2020/2021 with the Year 1 cohort. The teamwork data of students in these courses were collected over their three-year diploma course. The head of the then Academic Quality unit (AQ) was tasked to oversee its implementation. What began organically as one staff's personal project gaining traction with pockets of colleagues in different schools who continued using the teamwork measure after trying and finding it useful and easy to use, took a more

coordinated direction, with the AQ Head working with appointed staff in each school to track the implementation of the teamwork measure in each school's designated course.

In the "one-school-one-course" pilot phase, the focus was on the systematic measurement of teamwork skills for one class of students from one course in each school over their three years of study (or six semesters), with one teamwork measurement taken in each semester. The initial set of teamwork measurement data was collected and analyzed to assess its validity and reliability. Continual effort was made to gather a comprehensive dataset of six teamwork measures for the student cohort. All schools were invited to participate in this teamwork pilot project before the 2020 Academic Year (AY20/21). Eight courses responded to this pilot invitation.

### **Teamwork Measurement Implementation**

In this pilot, students conduct self-assessments (SA), and peer assessments (PA) of team members. In addition to administering the survey, LAMS has also been programmed by the vendor to compute the SPA (Performance factor) and SAPA (Self-Assessment to Peer Assessment) factors using the self and peer assessment data collected. LAMS also sends feedback reports to students after each SPA exercise. In addition, the lecturer downloads class reports from LAMS for developmental feedback to students and for grading teamwork contributions.

As the measurement of students' self-assessment and peer assessment of teamwork skills is planned once a semester over their three years of study, this works out to six teamwork measurements for each student. Figure 2 gives an example of the teamwork data measurement for students enrolled in the Diploma in Civil Engineering (DCE). The course team from DCE began by identifying six modules with substantial teamwork learning activities across the three-year course for the AY20/21 cohort of students. As illustrated in Figure 2, students carry out their teamwork assessments in BE8131 and BE8136 modules in Year 1; BE8231 and BE8234 in Year 2; and BE8307 and BE8335 in Year 3.

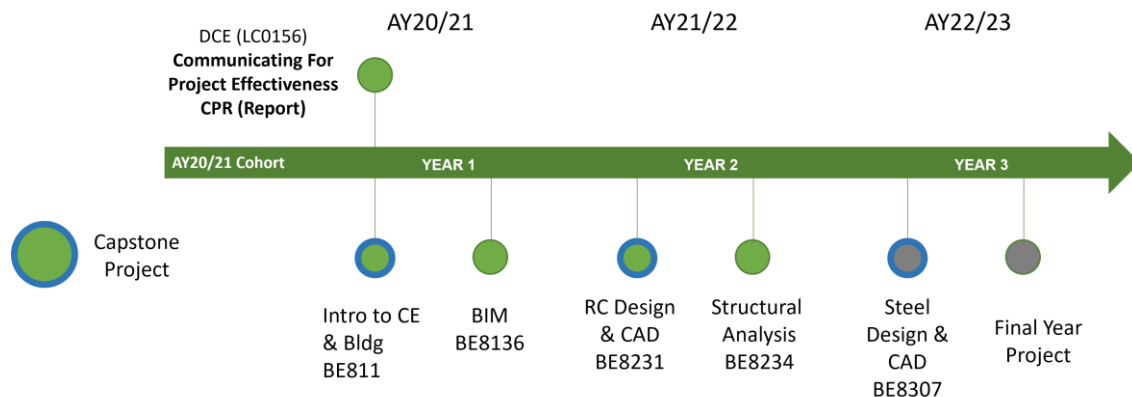


Figure 2. Teamwork measurement implementation

As it was made known to everyone involved at the start of the pilot phase that the final goal is to extend the teamwork measurement to all students, it was important that the pilot phase ascertained the usefulness of the teamwork measure assessment for participating students, prepare the ground, and gleaned the necessary input to develop the scale-up plan. The pilot

phase thus provided the space to learn through experimentation. The following sections discuss what we learnt about the usefulness of the teamwork measurement and instrument, the data collected to develop the scale-up plan, and which also affirmed SP's readiness to scale up.

### ***Usefulness of Teamwork Measurement Exercise and Instrument***

#### ***Staff and Students' Survey on the SPA Teamwork Measure***

In AY22/23 Semester 1, 16 staff teaching 40 SIP (Sustainable Innovation Project) module classes (comprising 836 students) piloted the teamwork measure in their classes over a semester while 26 staff and 46 classes (comprising 570 students) did so in the following semester, AY22/23, Semester 2. In both semesters, the teamwork measure was carried out in Week 6 (as a mid-semester or "formative" assessment) and in Week 17 (as an end-semester or "summative" assessment) in the 45-hour, 15-week, semester-long module.

At the end of each semester, a separate online survey was carried out with staff and students, to understand how they felt about using the teamwork measure as a lecturer and as a student. 13 out of 16 staff who took part in the AY22/23, Semester 1 pilot took part in the survey (a response rate of 81%). 5 out of the 11 new staff users (those who were not part of the pilot in Semester 1) took part in the Semester 2 survey (a response rate of 46% among the new users). Key findings from the staff survey for Semester 1 and 2 are shown in Table 1:

Table 1. Key Findings from Staff Survey at End of AY22/23, Semester 1 and 2

| No | Survey Questions                                                      | Strongly Agree/Agree ratings over a 5-point scale |                     |
|----|-----------------------------------------------------------------------|---------------------------------------------------|---------------------|
|    |                                                                       | AY22/23, Semester 1                               | AY22/23, Semester 2 |
| 1  | Important to have two SPA touchpoints (formative and summative)       | 92%                                               | 100%                |
| 2  | SPA supports my observations about students' teamwork skills          | 100%                                              | 83.4%               |
| 3  | SPA gives additional insights about students' teamwork skills         | 92%                                               | 100%                |
| 4  | SPA is useful for giving feedback to teammates on their contributions | 92%                                               | 100%                |
| 5  | SPA is useful in identifying 'free riders'                            | 85%                                               | 67%                 |
| 6  | SPA is useful for students to evaluate their own contributions        | 100%                                              | 83%                 |
| 7  | I want to continue using SPA                                          | 100%                                              | 100%                |

Staff feedback for the two semesters show a positive view of the teamwork measure as a useful tool for corroborating, and augmenting, their observations about students' teamwork skills and teamwork contribution, and in the value of the tool in allowing students to give feedback to one another and for self-evaluation. Most importantly, all express a wish to continue using SPA.

Table 2 shows key findings from the same end-of-semester survey conducted with students who took part in the teamwork measure pilot in Semester 1 and 2.

Table 2. Key Findings from Student Survey at End of AY22/23, Semester 1 and 2

|           |                                                                                              | <b>AY22/23, Semester 1</b>                                         | <b>AY22/23, Semester 2</b>                                         |
|-----------|----------------------------------------------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------|
|           | <b>Quantitative Feedback Received</b>                                                        | <b>(300 respondents out of a possible 836; response rate: 36%)</b> | <b>(222 respondents out of a possible 570; response rate: 39%)</b> |
| <b>No</b> | <b>Survey Questions</b>                                                                      | <b>Strongly Agree/Agree</b>                                        | <b>Strongly Agree/Agree</b>                                        |
| 1         | Used SPA before                                                                              | 78%                                                                | 73%                                                                |
| 2         | Find SPA easy to use                                                                         | 98%                                                                | 95%                                                                |
| 3         | Useful for giving feedback to <u>teammates</u> on their contribution to the SIP project      | 92%                                                                | 87%                                                                |
| 4         | Useful for evaluating their <u>own</u> contribution to the SIP project                       | 79%                                                                | 78%                                                                |
| 5         | Useful in identifying 'free riders'                                                          | 85%                                                                | 87%                                                                |
| 6         | Know how to interpret the SPA data they receive                                              | 87%                                                                | 84%                                                                |
| 7         | Find the Mid-Semester or formative SPA exercise helpful in identifying areas for improvement | 90%                                                                | 84%                                                                |

The key finding (Table 2, results for survey questions 3, 4 and 5) is that students in the SIP-SPA pilot found SPA a useful tool for giving feedback to teammates and for receiving feedback from teammates on their contribution to the team. This is corroborated by most qualitative comments given on how SPA allowed them to give honest (because it is anonymous) feedback to teammates and lecturer, and how it tells them what they can improve on and how they did as a team member.

Even more striking is the emphasis students gave on SPA as a feedback tool for self-improvement (“I learn to improve based on feedback I receive from my teammates”, “able to identify which areas I am strong in through positive feedback given”, “It helps me reflect on my contribution”, “Knowing what my teammates think about my performance allows me to work more on my areas of improvement”), as opposed to SPA being a tool for giving feedback to teammates on how *they* can do better.

Student feedback from both semesters suggest they find the SPA teamwork measure “convenient and simple to use” that it is an “easy platform to give feedback on” and that they would like to “keep using it in the future” if not “make it compulsory”. This is emphatic endorsement from students on the use of SPA in SIP.

### *Feedback from Companies*

SP also piloted the use of the SPA teamwork measure with 10 internship companies at the start of AY22/23, Semester 1. At the end of the internship program, an online survey was conducted with Supervisors and SP interns, to understand their internship-SPA experience.

We analyzed internship-SPA results, reviewed interns' SP-SPA records (where applicable, as not all interns had done SPA before in SP), and spoke with their lecturer in-charge and a company supervisor. Key findings are: internship-SPA results were consistent with SP-SPA results, and this suggests that the SPA teamwork measure could be a useful teamwork developmental tool while students are still in school; the SPA teamwork measure is especially useful at the workplace where team members have worked with each other for a period and can give meaningful feedback to one another; and the SPA teamwork measure has the potential to provide rich data for personal and team growth, and for staff development and appraisal at the workplace.

The positive and rich teamwork learning experiences from the internship-SPA pilot with companies adopting the self- and peer-assessment model was important validation for the use of the SPA teamwork measure in SP and for making it available to other modules. The favourable survey feedback from students, staff and industry provided a strong signal for scaling up the teamwork measurement to the entire student population.

### ***Institutional Scale-up Plan***

#### *Finding the Route to Scale*

During the one-school-one-course pilot phase, another institutional initiative, the compulsory, Common Core Curriculum (CCC), was also being rolled out. CCC aims to equip students for a rapidly evolving and unpredictable world. The opportunity to synergise the teamwork measurement initiative with CCC arose when it became apparent that three CCC modules; Collaboration in the Digital Age (CDA), Data Fluency (DF) and Social Innovation Project (SIP) involve learning in teams and would be keen to include the SPA teamwork measurement. The inclusion of these three CCC modules provided a high level of confidence that the teamwork measure institutional scale-up plan would be achievable as all students will carry out teamwork measurements in three CCC modules (indicated by orange coloured outline) and in at least three domain modules (indicated by black coloured outline), as shown in Figure 3.

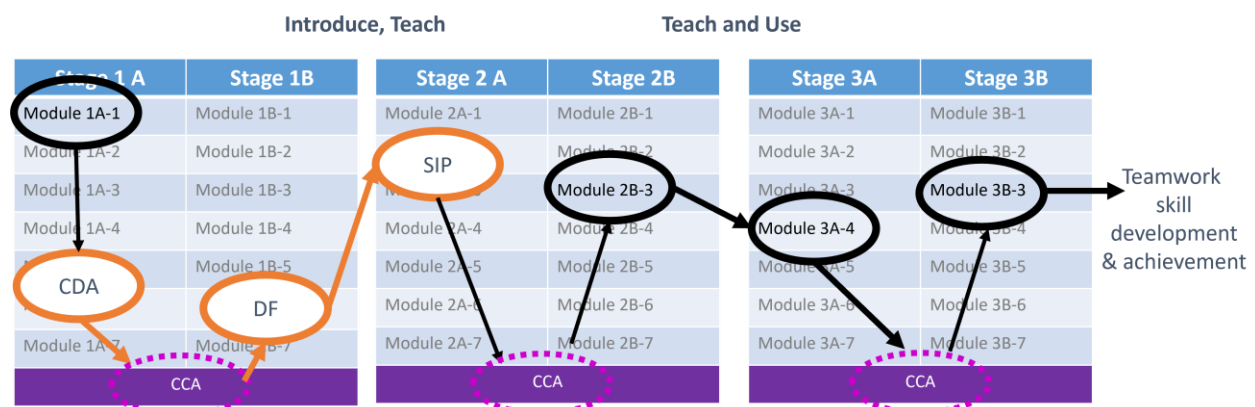


Figure 3. Route to institutional scale up by tapping on 3 CCC modules (CDA, DF and SIP)

### *Designing an Integrated Curriculum to Develop Teamwork Skills of Students Across Every 3-Year Diploma Course*

What is more important, with the inclusion of the Common Core Curriculum (CCC), is that all students will be on-boarded in a consistent and systematic way, through CDA (which aims to develop collaboration skills). In addition to the three CCC modules, the other domain modules are selected based on their suitability. Project modules and those employing relevant pedagogical approaches like team-based learning and problem-based learning are modules included in this scale-up plan. Through this institutional scale up model, a curriculum that facilitates the development and monitoring of teamwork skills throughout the three-year course was realized.

To confirm the exact number and specific modules to be included in the teamwork measurement scale-up implementation plan, the project team met with cluster teams consisting of school directors, as well as course teams. This collaborative effort resulted in the identification of at least six suitable modules for inclusion in every three-year course. In the scale-up phase, students will be introduced to the SPA teamwork measure and taught teamwork skills in the CDA module. They will then use and practise teamwork skills in SIP and other domain modules.

### *Implementing a Consistent and Rigorous Teamwork Skill Measurement Across the 3-Year Course*

In the institutional scale up, all students who join SP in AY23/24 and after, will be awarded a teamwork metric at the end of their three-year course. This makes it crucial that the teamwork assessments are consistently carried out throughout the institution. To facilitate a robust and consistent practice in the institutional roll-out, the following tools and practices were put in place: (1) a common teamwork measurement instrument was used. A common CATME instrument with the same five quantitative questions and teamwork assessment is conducted on the same LAMS survey system; (2) consistent on-boarding and teamwork skills development (introduce-teach-use) for all students through CDA, DF and SIP (compulsory CCC modules). Similarly, a consistent on-boarding through standardised training was also implemented for staff. All teaching staff who will be carrying out the SPA teamwork measurement in their module(s) are trained through the same workshop offered at institutional level and this consists of a half-day training that includes an overview of the importance of teamwork, and technical functions and features of the SPA teamwork tool from the students' and staff's perspective; and (3) a consistent and rigorous way of conducting teamwork measurement that comprises both "formative" and "summative" teamwork assessments. The exception is when it is a small module of 15 hours or when the module runs only in a particular term instead of over the entire semester. In addition, best practices for peer evaluation including the recommended flow for conducting SPA, are taught to staff.

### **Readiness to Scale**

To foster widespread participation in this institutional scale-up plan, it was crucial to instil confidence in staff and management by showing proof of the level of readiness. The level of readiness is demonstrated through the reliability and validity of measurement data, commitment of key stakeholders, capacity development and IT readiness.

### *Validity and Reliability Test of Measurement Data*

A quality teamwork measurement adds credibility and provides greater confidence when we use them. Two general criteria for evaluating psychometric measurements are reliability and validity (Jhangiani, Chiang, & Price, 2015). Significant correlations were obtained in the inter-rater and test-retest reliability of the teamwork measurements obtained from the pilot phase (Pee & Chue, 2022).

### *Commitment of Key Stakeholders*

To generate interest and commitment for the teamwork scale-up, multiple levels of engagements were conducted from May to August 2022. A total of 10 meetings were held with various stakeholders, including (1) School POCs (Points of Contact), (2) Principal Management Team, and (3) Senior Directors and Directors. The meetings served several purposes: progress updates for schools and institution, negotiations to reach common ground, securing buy-in, surfacing challenges encountered, encouraging participation and addressing requests for assistance. Two explicit outcomes were achieved from these engagements; the commitment to participate and the identification of modules in every course that would be included in the scale-up plan.

### *Staff Capability and IT Readiness*

The one-school-one-course pilot phase contributed to the development of staff and institutional capacity to effectively measure teamwork skills in each school, ensuring the availability of necessary resources and expertise to assess and enhance collaborative abilities within the educational environment. Additional training was offered to new staff joining the scale-up, conducted by an institutional SPA training team. Similarly, the ease-of-use of the SPA measurement on LAMS and the development of teamwork dashboards on LAMS, all serve to ensure staff and IT readiness, in support of the institutional roll-out.

## **INSTITUTIONAL SCALE-UP**

An institutional scale-up plan proposal including supporting data on (1) the usefulness of the teamwork measurement exercise and instrument; (2) a workable plan and (3) the readiness of staff and adequacy of resources was presented to PMT in 2022. The scale-up plan was supported and the greenlight was given for implementation in AY23/24 with the Year 1 cohort.

SP's Institutional rollout of the SPA teamwork measure innovation took time, a decade to be precise, from about 2013 to 2023, starting with one staff, before scaling-up to include the entire institution. It went through many phases, beginning with independent users of the teamwork measure sharing and exchanging information on an informal basis, before progressing to the one-school-one-course phase, and finally the campus-wide deployment of the teamwork measure phase. During the scale-up phase, further enhancements were made to the LAMS system to provide teamwork dashboards for lecturers and students so that they could monitor the students' or their own teamwork progress over time. As part of scaling-up, the institution is presently refining the computation of the Teamwork Metric to recognise the teamwork skill achievement, may be awarded to the AY23/24 cohort when they graduate in 2026.

## CONCLUSION

This paper presents a systemic account of the institution-wide scale-up framework for developing and measuring teamwork skills with the goal of sharing lessons learnt with educators who need to undertake similar projects and on this scale. Moving forward, data will be gathered to show the impact of the institutional roll-out of the teamwork measure in nurturing and tracking the achievement of an SP graduate attribute - collaboration skills in students in a systematic way, over three-years.

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# **BUILDING AN ENGINEER'LEARNER CURRICULUM IN THE LIFELONG LEARNING CONTEXT – PLE AND AI SUPPORT**

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## **ABSTRACT**

With the emergence of IT technologies, the proliferation and diversification of learning tools, engineering schools have diversified their approaches, technics and educational resources in order to improve student-engineers performance. Thus, they have invested in the implementation of learning management systems (LMSs) which offer each learner the opportunity to personalize their learning. However, this personalization always depends on techno-pedagogical constraints and the educational institutions orientations. Considering the LMS personalization limits, the personal learning environments (PLEs) have come to allow learners to individually develop their learning environment by selecting the right resources and appropriate activities without taking into account institutional constraints. This concept is in vogue especially in the context of lifelong learning which is one of the recommendations of the sustainable development goals (SDGs). Generally, the setting up of such an environment is not based on techno-pedagogical foundations (Choice of objectives, selection of curriculums, appropriate activities and resources). As a result, we are faced with situations where the learning is not aligned with learner prerequisites or where the training layout did not align with the content and learner expectations. So, the question that arose is: how can the learner define his learning objectives, to build an appropriate curriculum and effectively follow his training? In this context, we propose an assisted PLE integrating a recommendations system. With the concepts of AI and based on a dynamic questionnaire, the learner can manage to design, implement and operate his/her curriculum and be master of his/her own training (CDIO Initiative). In addition, educational resources compatible with the curriculum will be recommended and the learner will have to select one according to his preferences and abilities. Our paper fits into an active-learning context (standard 8 - CDIO).

## **KEYWORDS**

Lifelong Learning, Personalization, Personal Learning Environment (PLE), Recommendation System, Standard 8.

## INTRODUCTION

Our contribution consists of defining an approach to assist engineering learners to build their own curriculum without pedagogy prior knowledge, and to take autonomous control of their learning. It promotes lifelong learning (alignment with the SDGs) and falls within the "active-Learning context" (CDIO standard 8) framework. Three phases characterize our approach: the first concerns assistance in the identification of learning objectives and the recommending appropriate curriculum(s), the second will be the assistance in the search for appropriate activities to the objectives already set, and the last will be responsible for maintaining and managing the learner's profile. In this paper, we will only focus on the first phase; the purpose is to build a learner's own curriculum. To do this, a consistent environment must be able to provide assistance to engineering learners to identify and choose their learning objectives. It's based on a dynamic questionnaire that takes into consideration the profiles and feedback learners information. An educational learning objective according to IMS-Learning Design standard (Koper, 2005) represented by a couple formed by a concept (C) and a learning level (N): C being a concept belonging to a domain ontology  $\theta$  and N is one among the taxonomic levels in pedagogy (Bloom, Krathwohl, & Masia, 1984). Once the couple identified, our environment will be able to offer one or more curriculum(s) from a curricula corpus issue from different sources: educational and training institutions, and other resources (Cloud, OER, Moocs). A classification strategy using machine learning algorithms will then be applied to recommend appropriate curricula. Before going into the details, it would be appropriate to review the basic PLE theoretical foundations and the related work carried out in this area. We will first start by explaining the PLE concept, the PLE related work, and then we will present our assistance approach, subsequently our recommender system. We will end by presenting our experiment and the results obtained.

## THEORETICAL FOUNDATIONS OF A PLE

Personal learning environment can be considered as a concept related to the use of learning technologies emphasizing learner ownership of tools and resources. The questions discussed are: How does the learner use technology to manage his/her learning? How is individual activity captured? What are the distinctive characteristics of personal learning environment? This study supports the idea that PLE can be considered as complex activity system using the activity theory (AT) framework (Bal, et al., 2023; Buchem, et al., 2011).

### ***Activity Theory (AT) As An Integrated Framework***

The PLE concept emphasizes the appropriation of tools and resources by learners. The view of learning as a mediation tool or collective activity is the basic principle of activity theory (Bal, et al., 2023; Kuhn, 2017; Sharples et al., 2005; Scanlon & Issroff, 2005). Activity Theory (AT) has been used as a framework for exploring pedagogical innovations and as a conceptual framework for analyzing and designing support systems for collaborative learning (Kuhn, 2017; Couros, 2010; Holton, 2007; Engeström, 1987; Vygotsky, 1980; Ogden & Richards, 1923, for mobile learning (Kuhn, 2017; Sharples, et al., 2005) and for learning technologies evaluation (Kuhn, 2017; Alberio, 2001; Nardi, 1996).

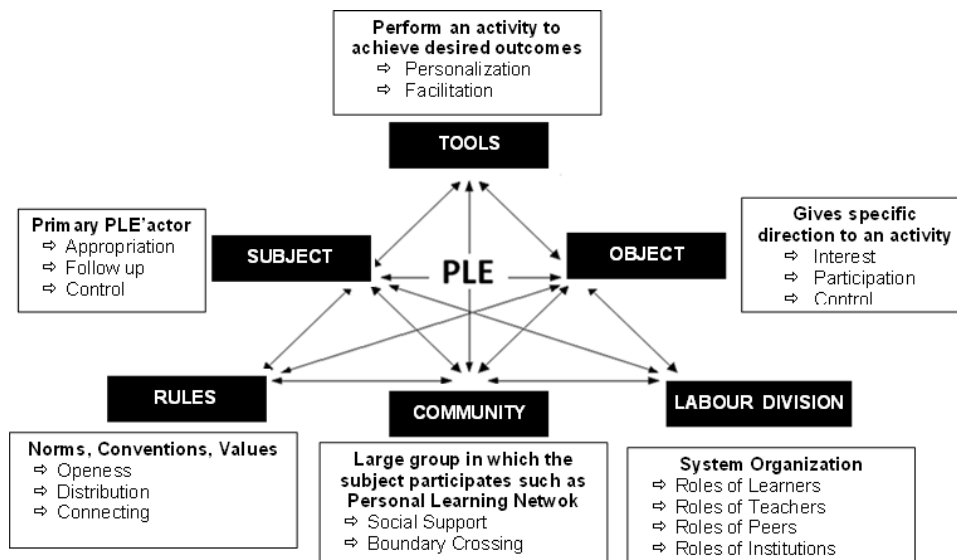


Figure 1. Summary of the PLE elements and its main dimensions

The study conducted by Buchem on a wide range of PLE publications, supports the idea that a PLE can be considered as a complex system of activities and can be analyzed using the framework of activity theory in order to describe its main components (Attwell, 2023; Bal, et al., 2023; Buchem, et al., 2011; Holton, 2007) (Figure 1).

### **PLE: Definition And Characteristics**

“A PLE is a learner-centered approach, based on web technologies and allowing support, control and appropriation of learning independently of technical and institutional constraints” (Guettat, et al., 2024; Guettat & Farhat, 2017).

Based on the views of (Guettat, et al. 2024; Chatti, et al., 2021; Yen, et al., 2021; Göksel & Mutlu, 2021; Martindale, et al., 2019; Guettat & Farhat, 2017; Göksel, et al., 2016; Chatti, et al., 2011; Martindale & Dowdy, 2010; Drachler, et al., 2008; Jafari, et al., 2006; Johnson, et al., 2006; Lubensky, 2008), PLEs should have the following characteristics:

- PLEs are open systems controlled by learners independently of the educational establishment.
- PLEs are customizable by learners.
- PLEs concentrate all the tools useful for the learner in a single environment.
- PLEs promote informal learning and lifelong learning.

As a result, it becomes clear that PLEs represent a turning point, from a model where learners simply consume information to one where learners become autonomous and create connections with a variety of resources that they select and curate themselves.

### **PLE Objectives**

Although some of the fundamental needs of users of PLEs have not yet been clearly defined, two major objectives have nonetheless emerged in the literature: a PLE must be centered on learner and should enable lifelong learning (Attwell, 2023; Bal, et al., 2023; Buchem, et al., 2011). These two goals align with the Sustainable Development Goals (SDGs).

## **LIFELONG LEARNING**

### ***Lifelong Learning Context***

Faced with the new landscape of educational technologies, learners continually face challenges in their learning. The speed of change as well as the growth of needs motivate learners to maintain the direction and extent of their lifelong learning. PLEs can be the appropriate solutions to these situations. These environments give learners the freedom to learn beyond course boundaries and institutional constraints, and customize their own learning environments before and during training. Additionally, e-Portfolios used by learners as a tool to trace their learning provide future employers an overview of the individual's learning history and results, skills and achievements. With PLEs, they allow learners to demonstrate their professional abilities in a continuous learning framework (Pan & Chen, 2023; Bal, et al., 2011; Chen, 2003).

### ***Lifelong Learning Vision***

The lifelong learning is the "Ongoing, voluntary, and self-motivated pursuit of knowledge for either personal or professional reasons. Therefore, it not only enhances social inclusion, active citizenship, and personal development, but also competitiveness and employability" (Leone, 2019; 2013), (Downes, 2019; 2018; 2010), (Guettat et al. 2024; Guettat & Farhat, 2013). The diffusing of the lifelong learning vision, signal the need for more personal, social and participatory approaches that support learners in becoming an active users and co-producers of his/her learning resources (Leone, 2019; 2013; European Commission, 2008). The emphasis on the shift from formal to informal e-learning through knowledge management and sharing has been placed, with particular attention to the PLE as learner-centered space. Nevertheless, the investigations are motivated by the many educational theories, implications and challenges that PLE concept has posed (Zhou, et al., 2020; Mcloughlin & Lee, 2010).

### ***Learner Centered Learning***

In a landscape marked by the evolution and emergence of educational technologies, and innovation in learning modes, models and methods, the learner is obliged to assume his/her tool choices to use and contributions intended to make in learning. Therefore, we need a learning model centered on learner, adaptable, flexible and specific, depending on the context, such that the learner will be able to control his/her individual choices in terms of the technologies to use by aligning them with his/her personal needs, interests, learning style, preferences and context. In this way, learner will know how to build and manage a personal and self-reflective learning environment rather than operating an environment constructed, managed and imposed by the teacher and/or institution (Attwell, 2023; 2007).

### ***PLEs Roles In the Lifelong Learning***

The PLEs give students the freedom to learn beyond course boundaries, and to personalize their own learning environment. They allow learners to learn anytime and anywhere. E-portfolios are currently used by learners in many education institutions as a tool to document and to reflect on their learning. They provide future employers with a snapshot of the learner's learning history, learning achievements, and reflective practice. (Drajati, 2020; Renon, 2012).

## Our Critical Analysis

Today's learning systems should break away from traditional learning methods because they can no longer satisfy everyone, especially with the perpetual evolution of technology. Other measures should be found to motivate learners to learn not only when they are in academic training, but also when they are independent. In our context, we are interested in lifelong engineering learners whose appropriation of learning can constitute a challenge for them. The solution that seems to be most appropriate is PLE. However, putting up personal learning environments requires solving a number of problems: How can the learner build his own personal curriculum? How does the learner profile will be maintained?

## OUR ASSISTANCE APPROACH

### Overview And Architecture

As part of our research in the field of PLE started in 2008, we have developed an innovative approach (Guettat, et al., 2024; Guettat, et al., 2013; Guettat & Farhat, 2017) allowing learners to build their personal learning environment, by building their own curriculums and choosing their appropriate learning activities. Such an approach will promote lifelong learning. To do this, we defined an architecture with three components: The "Curriculum builder", the "Learning activities recommender" and the "Profile manager" (Figure 2).

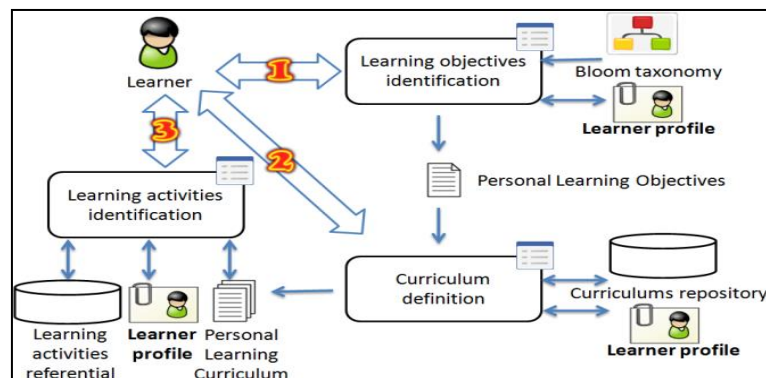


Figure 2. Overview of our Approach

### Modeling Learner

Nowadays, several specifications aim to describe the learner in learning environments: IEEE PAPI learner (IEEE P1484.2.1/D8, 2002), IMS Reusable Definition of Competency or Educational Objective Specification (IMS-GLC-RDCEO, 2002), IMS Learner Information Package (IMS-GLC-LIP, 2005), IMS Learning Information Services (IMS-GLC-LIS, 2011) and IMS Learning Tools Interoperability (IMS-LTI, 2015). However, no study has been conducted to assess whether any of those specifications is appropriate to the PLEs. So, we are concerned by finding a specification useful in the case of PLE in general and for our approach in particular. We have identified a requirements set of learner model: personal information, previous knowledge, learning traces, learning objectives and learner preferences. Based on our study we demonstrate how the IEEE PAPI standard is suitable for the case of our approach and in general for the PLEs (Guettat & Farhat, 2014).

## Assistance For Identifying Learning Objectives

### Objective Identification Process

This component helps learners to choose their learning objectives. We start by offering them a list of concepts so they can choose one: e.g. Mechanics, Computer Science, Management, Mathematics or Medicine. Each Concept has a sub-concepts list. For the “Computer Science” concept we propose “Algorithmics”, “Office Automation”, “Programming”, “Databases”, “Computer Architecture”, “Operating Systems” and “Computer Networks”. The choice of objectives will be based on an interactive dialogue with the learner using a dynamic and user-friendly questionnaire (Figure 3).

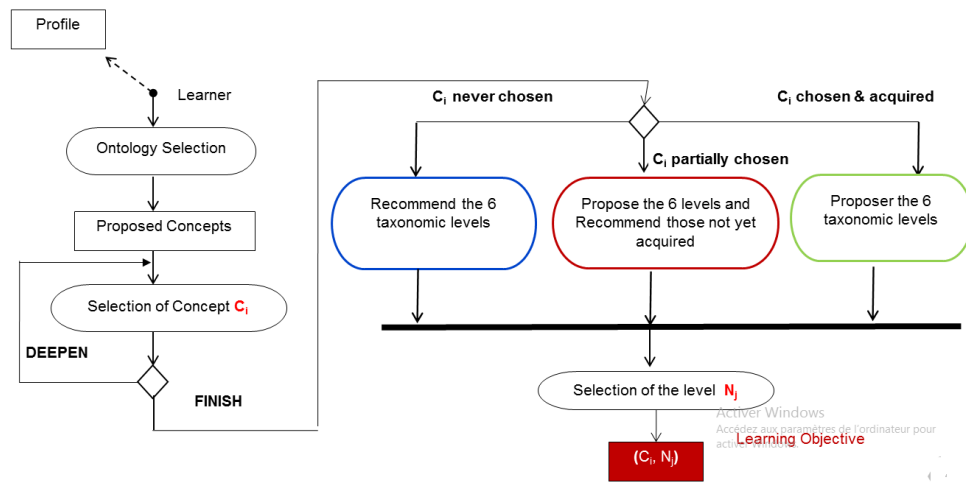


Figure 3. Objective identification diagram

### Assistance For Curriculum Selection

Once the choice is made (concept  $C_i$ , taxonomic level  $N_j$ ), the next step will consist of finding adapted curriculums. Two possible situations: The first, an exact match is found between the curriculum general objective and the learner learning objective and the second situation, we cannot find the right curriculum associated with the concept  $C_i$ .

#### First Situation: Exact Match Found

The selected curriculum will be used to identify the learning activities that must be accomplished by the learner. For example, we are looking for a course in “Computer Science” with a taxonomic level equals 2 (“Comprehension”); we found a bachelor's degree curriculum in computer science that matches. But in such a situation, several equivalent curricula may be found. Faced with such a situation, we will use concepts from Artificial Intelligence (AI) either to apply one of the classification algorithms to aggregate pieces of curriculums found, or to make a classification to recommend curricula to the learner (Di Ciaccio et al., 2012; Morineau et al., 1995). Based on our contribution which improved the IEEE-PAPI learner model in a PLE context, we are detecting significant and useful variables (features) for classification (Table 1).

Table 1. Sample of variables (Features)

| Variable | Codification | Description                                                  |
|----------|--------------|--------------------------------------------------------------|
| V1       | LANG         | Learner's preferred Language: Fr, Ang, Ar, All, Esp.         |
| V2       | TYPF         | Desired Type of Training: Quick, Medium, Long.               |
| V3       | NBUC         | Uses Number of a given curriculum.                           |
| V4       | NBAC         | Number of completions on a given curriculum.                 |
| V5       | RACC         | Completion ratio on a given curriculum. (RACC = NBAC / NBUC) |
| V6       | NBOB         | Number of objectives in a given curriculum.                  |
| V7       | NATC         | Average of marks awarded by learners on a given curriculum.  |

In figure 4, we present a diagram describing the process of obtaining a personal curriculum.

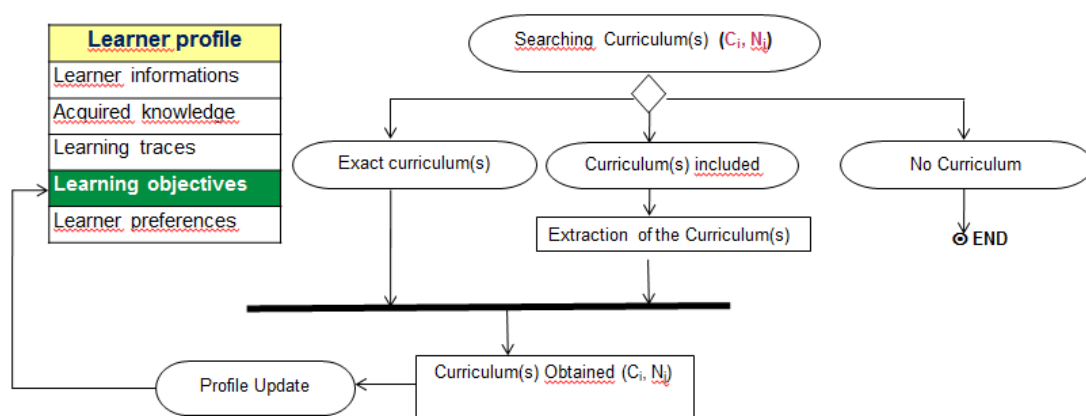


Figure 4. Curriculum selection diagram

### Second Situation: Right Curriculum Not Found

For example, we are looking for training in BCNF (Boyce Codd Normal Form), but our system found nothing in the corpus. In this case, we need to go down the ontology and go to the “Normalization” node. It would then be necessary to work on the content of each curriculum concerning this node using its XML file and see if the associated block with the BCNF concept exists. The same thing here, we can find several equivalent blocks corresponding to our concept  $C_i$  and we must choose the most appropriate according to a classification strategy with always the same sample of variables.

## EXPERIMENTATION AND RESULTS

In this section we will experiment a part of our approach (Identification of personal learning objectives and Curriculum recommendation). We have developed an assistant system, which allows any learner to use services offered without any technical or institutional constraints.

### Web Architecture

This is web architecture with a client using a browser (e.g. Chrome) containing our system which will allow the learner to compose a personal curriculum and obtain the list of appropriate activities (Figure 5).



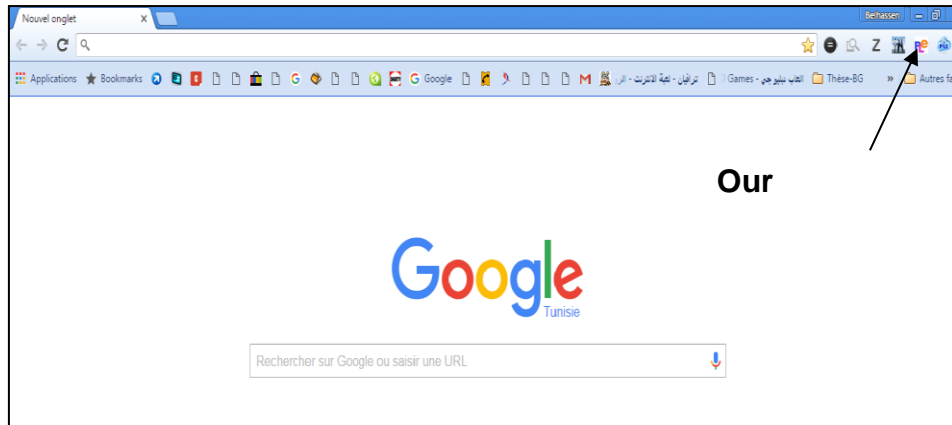


Figure 5. Our Assistant Interface

By clicking on the "PLE" Assistant, the learner could benefit from offered services system: identifying learning objectives assistant, curriculums recommender and activities recommender (Figure 6).

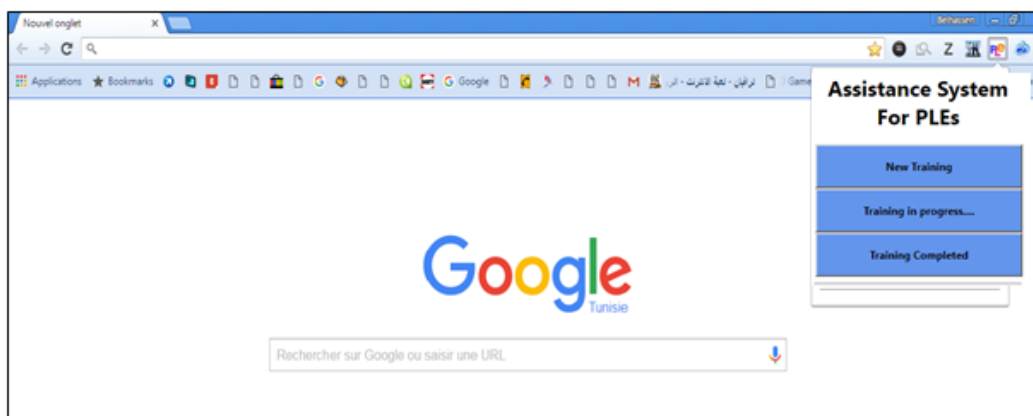


Figure 6. Services offered by our assistant

### ***Assistance In Identifying Learning Objectives***

#### ***Input Data Set***

To experiment with this component, we had the following data sets:

- Set of learner profiles with different scenarios: Learner has never completed learning in a given concept, or has partially completed learning at given taxonomic levels, or has completely completed learning in a concept.
- Sample of learners requesting new learning curricula.
- A corpus of curriculums: Each curriculum concerns a well-defined concept.

#### ***First Situation: Learner wants to Learn "Databases" with Taxonomic Level 1***

Our system will offer him all the curriculums (DB, 1) from our corpus. Which one will we recommend to him? Firstly, our system will make a filter by taking into consideration the learner requirements and his/her profile. After that, our system will execute the machine learning (ML)

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algorithm (Hierarchical classification algorithm). After notification of the variables, we obtained a curriculum list from our curriculum corpus including those dealing with “Databases” concept and the taxonomic levels. Given that the learner is interested in learning (“DB”, 1), the system extracts from our corpus all the “DB” curriculums with taxonomic level equals 1 (Table 2).

Table 2. Extraction of curriculums related to (BD, 1)

| Concept | Level | LANG | TYPF | NBOB | NBUC | NBAC | RACC  | NATC  |
|---------|-------|------|------|------|------|------|-------|-------|
| DB      | 1     | 1    | 1    | 2    | 1855 | 1000 | 0,539 | 06,20 |
| DB      | 1     | 1    | 1    | 2    | 2500 | 1500 | 0,600 | 08,00 |
| DB      | 1     | 0,66 | 0,66 | 3    | 1985 | 600  | 0,302 | 05,40 |
| DB      | 1     | 0,5  | 1    | 2    | 750  | 300  | 0,400 | 04,80 |
| DB      | 1     | 1    | 0,66 | 3    | 2265 | 1265 | 0,558 | 06,10 |
| DB      | 1     | 1    | 0,33 | 5    | 4578 | 4000 | 0,874 | 08,70 |

Which curriculum(s) our system will recommend to learner? The ML algorithm will calculate the similarity distances; before, it converts all the values in the interval [0..1] (Table 3), and sorts the curriculums in ascending order according to  $d^2$  rubric (Table 4).

Table 3.1 Sample of variables (Features) reduced to [0..1]

| Concept | Niveau | LANG | TYPF | NBOB | NBUC | NBAC | RACC  | NATC |
|---------|--------|------|------|------|------|------|-------|------|
| DB      | N1     | 1    | 1    | 0,00 | 0,19 | 0,13 | 0,539 | 0,70 |
| DB      | N1     | 1    | 1    | 0,00 | 0,26 | 0,19 | 0,600 | 0,90 |
| DB      | N1     | 0,66 | 0,66 | 0,33 | 0,21 | 0,08 | 0,302 | 0,61 |
| DB      | N1     | 0,5  | 1    | 0,00 | 0,08 | 0,04 | 0,400 | 0,54 |
| DB      | N1     | 1    | 0,66 | 0,33 | 0,23 | 0,16 | 0,558 | 0,69 |
| DB      | N1     | 1    | 0,33 | 1,00 | 0,47 | 0,50 | 0,874 | 0,98 |

Table 4. ( $d^2$ ) sorted in ascending order by ML algorithm

| Concept | Level | LANG | TYPF | NBOB | NBUC | NBAC | RACC  | NATC | distance ( $d^2$ ) |
|---------|-------|------|------|------|------|------|-------|------|--------------------|
| DB      | N1    | 1    | 0,33 | 5    | 4578 | 4000 | 0,874 | 0,98 | <b>00,979</b>      |
| DB      | N1    | 1    | 0,66 | 3    | 2265 | 1265 | 0,558 | 0,69 | <b>02,060</b>      |
| DB      | N1    | 1    | 1    | 2    | 2500 | 1500 | 0,600 | 0,90 | <b>02,296</b>      |
| DB      | N1    | 0,66 | 0,66 | 3    | 1985 | 600  | 0,302 | 0,61 | <b>02,720</b>      |
| DB      | N1    | 0,5  | 1    | 2    | 750  | 300  | 0,400 | 0,54 | <b>03,507</b>      |
| DB      | N1    | 1    | 1    | 2    | 1855 | 1000 | 0,539 | 0,70 | <b>02,632</b>      |

As we noted, the curriculum with the lowest distance will be recommended, in our case, it is the curriculum (BD, N1) with distance  $d^2=0.979$ .

*Second Situation: Learner having “DB” levels 1 & 2 wants a “BCNF” Level 1 Curriculum*

Our system searched in the corpus but found nothing. He turned back to his domain ontology to go back one level. There, we found the concept “Normalization”. We know well that the

BCNF concept is one of the normal form encountered in database courses, containing the "Normalization" chapter. We will therefore search all the Normalization curricula and detect the presence of the specific objective relating to the Boyce and Codd normal form. This means the system will work on the curriculum content (XML file) which its metadata is made up of the following sections: Concept, Level, Language, Training Type, Objective Number, Description, List of specific objectives.

To find the concept, the system will process the list of specific objectives contained in the XML files. As soon as we find `concept_objs = "BCNF"`, it will select the corresponding curriculum. After processing on the already selected curriculums, we marked those which contain the concept "BCNF". Following this processing, we obtain the following four curriculums (Table 5):

Table 5. List of obtained curriculums

| Concept           | Level | LANG | TYPF | NBOB | NBUC | NBAC | RACC  | NATC | distance (d <sup>2</sup> ) |
|-------------------|-------|------|------|------|------|------|-------|------|----------------------------|
| Normaliz<br>ation | N3    | 0,66 | 0,66 | 0,33 | 0,47 | 0,19 | 0,396 | 0,98 | <b>01,978</b>              |
| Normaliz<br>ation | N1    | 0,5  | 0,66 | 0,33 | 0,15 | 0,13 | 0,821 | 0,67 | <b>02,433</b>              |
| Normaliz<br>ation | N1    | 1    | 1    | 0,00 | 0,13 | 0,13 | 0,977 | 0,46 | <b>02,818</b>              |
| Normaliz<br>ation | N4    | 0,66 | 0,66 | 0,33 | 0,00 | 0,00 | 0,000 | 0,00 | <b>04,676</b>              |

The learner is looking for a BCNF curriculum with level = 1, our system recommends two but the one with  $d^2 = 0.2433$  will be best recommended.

### Results

Nearly, a hundred learners enrolled in the first year of IT engineering took part in the experiment. At the first, they passed a pre-test to divide them in two similar groups according to their level. After that, the two groups were invited for a test (in the same day: 2 hours). We asked the learners to solve the same exercise (about relational databases normalization) by creating their own PLE. Each learner in the control group has to build his/her own PLE and therefore to solve the given exercise. However, learners in the experimental group have access to our assistance system installed in their web browser. To evaluate the effectiveness of our approach, we measured the time and scores obtained by the group that used an unassisted PLE and the one who used an assisted PLE. We observed firstly the time of realization for the same activity to the two groups (Control and Experimental) (Table 6).

Table 6. Average of Times Activity

|      | Group        | Number of Participants | Average (mn)    | Standard deviation |
|------|--------------|------------------------|-----------------|--------------------|
| Time | Control      | 50                     | <b>108,4000</b> | 10,20022           |
|      | Experimental | 50                     | <b>20,8333</b>  | 2,00144            |

The results confirm what we observed on the premises: the learner in the control group wasted a lot of time to find the appropriate resources to carry out the activity. We conclude

that with an assisted PLE there is a gain in required learning time. On the other hand, we obtained the scores obtained by the two groups (Table 7).

Table 7. Average of Scores Activity

|        | Group        | Number of Participants | Average (mn) | Standard deviation |
|--------|--------------|------------------------|--------------|--------------------|
| Scores | Control      | 50                     | 7,85         | 5,71086            |
|        | Experimental | 50                     | 14,64        | 1,64485            |

We find that the mean of the control group is 7.85 with a standard deviation of 5.7. On the other hand, the results obtained in the experimental group are much better. Indeed, the average score is 14.6 (almost the double) with a small standard deviation compared to that observed in the control group. This clearly shows that the use of an assisted PLE improves the learners' performance.

## CONCLUSION & PERSPECTIVES

Nowadays, the use of Internet and especially the web is a part of our everyday activities. Web resources and tools are frequently used for learning. To learn anything the learner can look for the appropriate resources by asking peers in social medias or by using search engines for examples. The resources and tools chosen by the learner to learn can be considered as a PLE. In this paper we have presented a new approach to build assisted PLE for engineer-learner based on the artificial intelligence concepts (Machine Learning algorithms). The goal is to simplify the PLE building process and increasing the learning process efficiency.

To reach this goal, we began by discussing the limits of personalized learning environments, mainly because the institution generally imposes the choice of these environments, their content and the integrated educational tools. This situation can satisfy certain categories of learners but it can demotivate others, especially in the context of lifelong learning. From this came the concept of a personal learning environment (PLE).

We first distinguished between personalized environment and personal environment, we briefly reviewed the research work in PLE and noted that this concept has not reached the stage of maturity since those who have worked on this offer different visions and orientations. Even in the CDIO conferences, which started since 2005, and until 2023, this concept has not developed in the different participants acts and has never appeared in the different proceedings.

One of our contribution consists providing a clear definition of a PLE after an analysis and study of hundreds of scientific productions. The question that subsequently arose is how to find a method that will allow the learner to create their own PLE, because some who have tried to do so have sometimes missed their target because the tools chosen did not allow them to do so, to continue their learning and therefore they were not able to achieve their objective. Add to this their educational limitations, which prevent them from choosing an appropriate objective or curriculum.

Faced with this observation, we decided to develop an assistance approach, which will allow learners to build their learning curriculum in a context of lifelong learning, based on the concepts of PLE and AI.

So, we have developed a PLE assistance system and experimented it in a real situation. A significant sample of students enrolled in the first year of Engineer 'studies at Tunisia Higher School. They were divided in two groups: experimental and control. The results show that when using an assisted PLE learning time is shorter and scores are better than using a classical PLE.

For the perspectives, we are currently working on the problem of updating the learner profile when performing learning activities. In particular, we questioned the ability to evaluate success or failure when the learner accomplishes an activity. In a traditional e-learning system the activities are designed in a way to allow the collect of results by the system. In PLE we do not have such this control on activities.

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# COMPETENCIES-BASED LEARNING MODEL DEVELOPMENT FOR A CYBER-PHYSICAL SYSTEMS IMPLEMENTATION

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## ABSTRACT

We might wonder about the professional motivations that drive students to pursue electromechanical (EM) engineer graduate studies. In this sense, we approach the notion of professionalization not only in the field of work, but also in the field of education, so that teachers and learners confront work situations and articulate work and training more closely within the framework of multiple specialisations in a dynamic environment. In this framework, a Competencies-Based Learning (CBL) approach was developed to list, prioritise, and complement competencies of the reference job repository of an EM engineer with the learning outcomes to cover the training areas through the specified curricula (Standards 1, 2). These competencies were transformed during the developing process of a learning factory established by a Cyber-Physical Systems (CPS) to meet the training needs of an EM engineer in a pedagogical environment faced with a professional situation (Standards 5, 6, 7). For an EM engineer, we study the different situations encountered and experienced by the learner and draw up a list of specific professional skills encountering different layers of the pyramid of automation and industry 4.0 by referring to our technological installations within spaces set up for this purpose. A synergistic process between the different technological layers has been set up to support the learning process to match the targeted learning outcomes through the technological aspect defined via the CPS platform in an iterative process (Standards 3, 4, 8). Thus, a modular CPS platform is adapted to an engineer work environment and fed by real industrial projects ensuring knowledge, skills, and attitudes necessary to CDIO framework implementation.

## KEYWORDS

Competencies-Based Learning, Cyber-Physical Systems, Professionalization, Electromechanical Engineer, Integrated Learning, Standards: 1, 2, 3, 4, 5, 6, 7, 8

## **INTRODUCTION**

Faced with students' preoccupation with teaching practice, we might well wonder about the professional motivations that drive them to pursue graduate studies. Are they really looking for training in scientific research when they can also be trained in work situations in their academic environment? In this context, we approach the notion of professionalization not only in the field of training, but also in the field of work, so that teachers and learners confront work situations and articulate work and training more closely within the framework of multiple specializations and in a dynamic context. This paper is structured as follows. First, we describe the CBL approach implementation for CPS education. Indeed, we follow-up pedagogical research of the EM department to integrate its CBL approach into its curricula. For a CPS model competencies are crossover for a better professional integration. The second session concerns the CPS competencies generation for a pedagogical scheme implementation. A case study session is developed to lead to a discussion of primary results. Finally, we conclude the main work and give insight into few perspectives.

## **CBL APPROACH FOR CPS EDUCATION**

To analyse this dialogue between the different situations encountered by the teacher, it is necessary to trace the epistemological logic underlying the training system and the constituent elements of its "professionalizing" structure, studying the different situations encountered and experienced by the learner and drawing up a list of specific professional skills. In this sense, we note the aspirations of EM engineering students in relation to the skills required by the job market. In this way, a professionalization action enables the implementation of the skills in the referential through involvement in the action. To this end, we conducted a study based on a competency-based approach inspired by the work of Rezende et al., (2023) who resigned the CBL approach with the CDIO framework.

### ***Electromechanical CBL Approach***

Thanks to an international market study, we have compared the competencies of the reference job repository of an EM engineer with the learning outcomes to try and cover the training areas. To this end, the Electromechanical Monitoring and Steering Committee (MSC) conducted the study by developing a space for construction and exchange between teachers. The committee ensured the adequacy between the training and the professional profiles so that an engineer fulfills this role in an efficient way. The analysis of the results of the market survey, conducted with professionals, showed consistency between the established skills and a complementarity and continuity ensured between the different modules taught. We also took care to establish the link between skills and learning outcomes on the one hand and learning outcomes and activities on the other. A competency framework has been established. The MSC compared the skills of the generated reference system and its components with the learning achievements to try to cover the areas of training. Indeed, a work on competencies' census, crossover and integration was launched to take charge of the skills targeted in the training through the learning achievements that evoke the heart of the EM curricula. To support the competency-based approach, we have identified the micro-competencies of professional situations, through graduates' testimony and final grade students' skills profile in their work situation. Thus, we support feedback for associated training situations' generation. To align our approach with the targeted professional skills, we declined EM engineer profile throughout curricula, mainly focused on the CDIO framework for the mechanical, electrical and information sciences sectors, particularly to deal with complex and modern issues. Through this work, we

have made sure to establish the articulation between skills and learning achievements on the one hand, between disciplinary fields and professional profiles and finally between learning achievements and learning activities. The proposed CBL approach delivered these skills and enables us to set up reliable and effective learning paths. In fact, the method implemented is an organizational model designed to target and evaluate professional skills while optimizing human and material potential. This method allows us to predefine our needs and to make the student aware of the relevant professional competencies while allowing to visualize the inputs of his activities, its outputs, and its multidisciplinary impact by knowledge, attitudes and acquired skills according to the project and the level of the learner throughout his studies.

### ***Competencies crossover through a CPS model***

Industrial sectors are quickly implementing the industry 4.0 vision and related technologies to capitalize on the development of intelligent cyber-physical systems and operations. Some industries, like manufacturing, have made headway in creating digitalization plans, executing pilot programs, and bringing the industry 4.0 concept to life. Although CPS engineering is an emerging field, industry and society have defined their expectations and requirements for establishing CPS education and qualifications that engineers need to have to succeed in their profession, and what knowledge and skills are not sufficiently developed after completing engineering education (Francalanza et al., 2017; Kannengiesser et al., 2021; Meng et al., 2023; Thramboulidis, 2015; Törngren et al., 2017; Wu et al., 2019). The unifying conclusion drawn from these researches is that CPS engineers require a thorough understanding of CPS, strong foundational knowledge of CPS engineering, and a strong set of social and methodological abilities. Other research of the CDIO community provide an overview of anticipated educational needs, the current state of the art in education, and an analysis of the subject of CPS to comprehend the implications for education. Indeed, recent studies highlight critical issues in curriculum design, such as balancing depth and breadth, theory and practice, academic and industrial needs, and core technical skills with complementary skills (Mäkiö et al., 2021; Meng et al., 2023; Rezende et al., 2023; Yudin et al., 2021; Zabasta et al., 2020). To acquire these skills, the engineering student must study the fundamental subjects and the engineering sciences with in-depth studies proposed for different optional specific courses starting from the first year of engineering cycle. The student accrues fundamentals and practical skills of the generated competencies as part as the developing process of the CPS pedagogical platform as part of CDIO 6<sup>th</sup> Standard (Kulkarni et al., 2020; Martseva et al., 2021; Rezende et al., 2023; Yudin et al., 2021).

Based on our CBL approach, CPS competencies throughout an EM engineer's curriculum were identified. Thus, learning paths with several level of depth were developed and implemented. In fact, Table 1 describes the evolution of skills generated when moving from one learning level to another from the first to the third grade. Each course requires a specific competencies acquisition path (Understand and master, Design and innovate, Act, manage and implement, Transversal skills). In this way, we represent a cross-reference of the main skills generated with their rate of intervention in each course of the CPS chain throughout the learning cycle. The rate of intervention is cross-referenced with the level of depth required to acquire a given competency. The "+" mark describes the importance of this cross-reference, so that "+" and "+++" represent the lowest and the highest level, respectively.

Table 1. Main courses for CPS chain implementation and Competencies crossover

| <i>Learning grade</i>             | <i>CPS courses /Competency</i> | <i>Understand and master</i> | <i>Design and innovate</i> | <i>Act, manage and implement</i> | <i>Transversal skills</i> |
|-----------------------------------|--------------------------------|------------------------------|----------------------------|----------------------------------|---------------------------|
| 1 <sup>st</sup>                   | Electrical systems             | +++                          | ++                         | ++                               | +                         |
| 1 <sup>st</sup>                   | Additive manufacturing         | ++                           | +++                        | ++                               | +                         |
| 2 <sup>nd</sup>                   | Quality control                | ++                           | +                          | ++                               | ++                        |
| 2 <sup>nd</sup>                   | Robotics                       | ++                           | ++                         | ++                               | ++                        |
| 2 <sup>nd</sup> & 3 <sup>rd</sup> | IoT & Mobile robotics          | ++                           | +++                        | +++                              | ++                        |
| 2 <sup>nd</sup> & 3 <sup>rd</sup> | Automation & Supervision       | ++                           | +++                        | +++                              | ++                        |
| 3 <sup>rd</sup>                   | Sustainable energy             | +                            | ++                         | +++                              | +++                       |

For each course, a scenario for implementing the learning path is generated to match the targeted educational objectives through the technological aspect defined via the CPS platform in an iterative process throughout the curricula. Indeed, targeted competencies are identified for the appropriate learning situation throughout a recommended skill's level spectra for a reliable implementation. In fact, Table 2 below shows a corresponding approach for the "Electrical systems" course, described above. Learning-teaching paths are generated for a reliable technical-pedagogical CPS implementation. Moreover, to respect the distribution of technical skills and their chronological and practical aspects, we set up an integrated professional learning path with its own pedagogical implementation for an integrated learning experience (CDIO Standard 7).

Table 2. Extract of electronic learning-teaching path for a specific skills' level

| <i>A learning outcome</i>                                                                                                                      | <i>Skill level</i>                                        | <i>Learning situation</i> |
|------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|---------------------------|
| Ability to model physical phenomena related to electrical energy production, transportation, distribution, conversion, storage, and management | Know the standards of electrical networks                 | Interactive course        |
|                                                                                                                                                | Understand a specific electrical diagram                  | Problem based Learning    |
|                                                                                                                                                | Create an electric installation based on specifications   | Project                   |
|                                                                                                                                                | Evaluate compliance of an electric installation standards | Peer review               |

This work is carried out for each learning outcome integrated into each course through the CPS learning path to align the training objective, learning situation and teaching methods.

## **CPS COMPETENCIES CROSSOVER FOR PEDAGOGICAL IMPLEMENTATION**

At this level, the aim is no longer to start from a specialist issue, but rather to map out a learning path and the acquisition of well-defined skills based on the CDIO framework.

## **CDIO Standards for CPS Education**

The particularity of the CDIO approach lies in the practice-oriented training of engineering students, which is the very purpose of this study, which describes the development of a method for setting up a practical CPS workshop based on a CBL approach. In fact, the main objective of modern technical education is to train students for successful professional activity, by developing their professional skills through targeted and concrete learning activities.

The implementation of the CDIO framework in the ESPRIT electromechanical workspaces through the CPS via the Siemens Tia portal presupposes the improvement of engineering education at international level, delivered in the regular context of industrialization of real systems. Through CPS, students develop skills in the design, implementation, and operationalization of processes, and apply theoretical knowledge in real engineering practice, solving educational and practical tasks for the design and creation of products and systems integrated into the curriculum. In fact, the first standard presents the concept of CDIO and assumes that what should be taught in engineering schools depends on how complicated an engineering task is as demonstrated throughout our process. Further, the standards for educational outcomes are stated in Standard 2. This component has been upgraded and changed using the CBL approach to better prepare for engineering challenges. As per Standard 3, the curriculum that has been designed is integrated, meaning that it incorporates connected disciplines and a tight plan for incorporating interpersonal and personal competencies with product, process, and system design abilities. The existence of an initial "Introduction to Engineering" course in the educational program is defined by the Standard 4, which lays the groundwork for the engineering practice's decline in a variety of pedagogical scenarios that lead to the CPS platform's pedagogical objectives.

From a practical point of view, the curriculum of a CPS educational program includes more than seven projects (Robotics, Supervision, IoT, Advanced automation, automation, 3D printing, Quality control, etc.) at the basic and advanced level (Standard 5). In fact, the CBL approach is based on integrated projects as a means of consolidating basic science and reducing the gap between theory and practice. Indeed, the requirement to provide enough workspace for students to gain practical engineering, social interaction, cooperation, and independent work skills led to aim the Standard 6. This standard serves as our final basis for building these collaborative places, as we covered in section *Pedagogical implementation through a collaborative model*. Besides, Standard 7 requires that throughout our CPS implementation to refer to instructional strategies that support the development of engineering, interpersonal, and personal capabilities in addition to skill acquisition for integrated learning strategies as well as for active and successful practice-oriented approaches (Standard 8).

### **Technical-Pedagogical implementation**

The place given to full-scale, accompanied experiential learning regarding future professional skills. The approach is aligned with the corresponding industrial-scale processes and systems, and the respective skills required for development and operation. The approach described has been validated by application in a team project at university as part of an EM engineering robotics, automation and supervision modules. To implement the practical aspects of the CPS, hardware and software products have already been implemented in collaboration with the Siemens Automation Cooperates with Education (SCE) for a "Totally Integrated Automation" (TIA) Portal installation (Figure 1). Under this program, students and teachers have the opportunity to get "Advanced" or "Expert" Siemens certifications. To align professional required skills with workshop learning situations, a realistic model-scale process was selected from

among others and enhanced to suit the dedicated learning objectives. Indeed, the CPS pedagogical implementation strategies are based on the CBL approach and pedagogical alignment already developed in section *Competencies crossover through a CPS model*. The CPS line was built around the operative part as illustrated in Figure 1 and based on four processes as shown in Table 3.

The laboratory workstation is controlled by a personal computer via a USB interface, using either off-the-shelf software tools or software created through advanced integration in the field of graphics programming. To ensure pedagogical and technological consistency, the two main parts of the cyber-physical platform have been developed. In fact, the “Cyber” part is implemented through “The Industrial Performance Starter Pack 4.0” (Figure 1.a.). It enables students to test value through use, and thus accelerate their thinking on use cases that will improve the industrial performance of the case studied. The “Physical” part of the CPS platform is the robotic cell “MITSUBISHI RV-2FR-D-S25 6-axis system” (Figure 1.b.). It is the most complex and flexible handling device in an industrial environment upgraded with RFID, Energy Meter, and a servo drive Sinamics S210 for industrial automation systems simulation. By another hand, collaboration between technological aspects has been integrated through digital twins. This technological framework has enabled a multidisciplinary approach removing the barriers between different CPS courses previously described in Table 1.

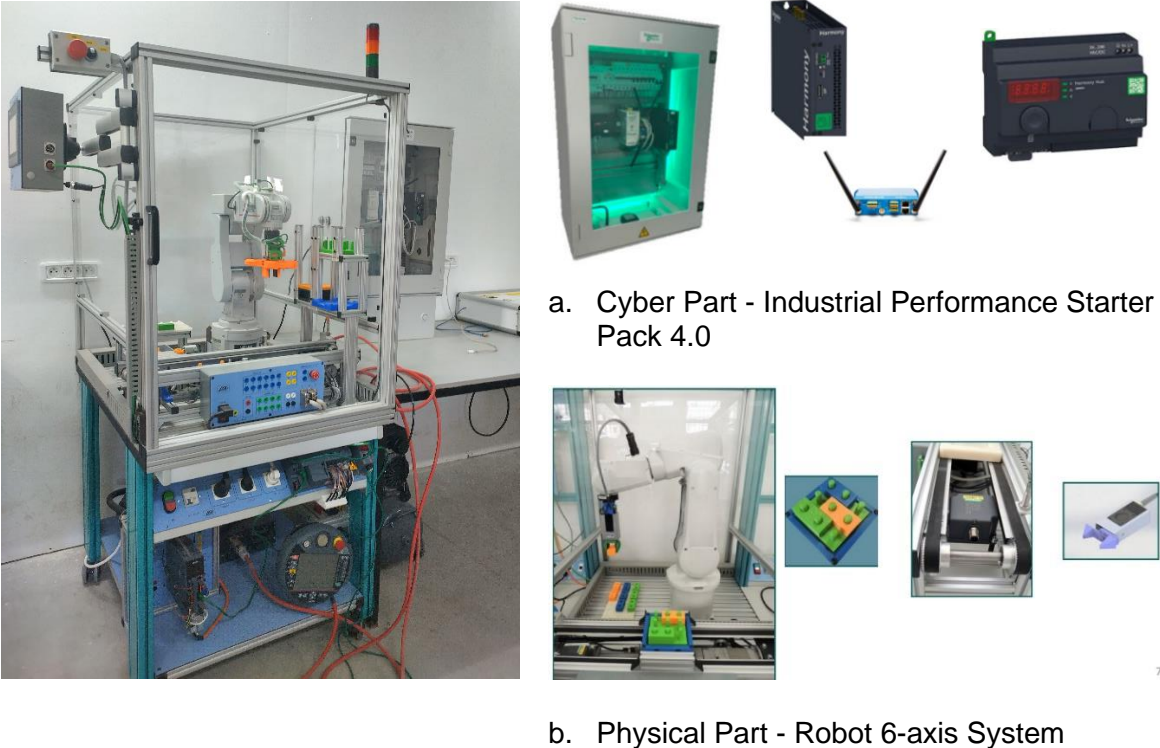


Figure 1. The operative part of the CPS platform via the TIA Portal and the SCE for pedagogical implementation

For instance, the practice scenarios in Table 3 are based on guidelines. The illustrated learning paths involves Additive Manufacturing (3D printing technology), followed by a robotized assembly line, to parade assembled parts according to specific patterns onto a part quality control platform via a manufacturing execution system with the intervention of an autonomous

robot system that manages a supply store for inventory management. Each practice session is divided into several sections. Each section is made up of several practical workshops that include theory, homework, practice, and instructions to cover the learning outcomes. Preliminary design work precedes each workshop, helping the student to better understand the operation of the elements studied. The "+" mark describes the CPS competencies fulfilment, so that "+" and "+++" represent the lowest and the highest level, respectively.

Table 3. Rating of processes regarding CPS for competencies fulfilment

| <i>Process regarding CPS components</i>                       | <i>Physical</i> | <i>Data Acquisition</i> | <i>Cyber</i> | <i>Feedback/Control</i> |
|---------------------------------------------------------------|-----------------|-------------------------|--------------|-------------------------|
| Additive manufacturing (3D printing technology)               | +++             | +                       | +            | ++                      |
| Robotic assembly line                                         | +++             | ++                      | +            | ++                      |
| Quality control of parts via a Manufacturing Execution System | ++              | +++                     | ++           | +++                     |
| IoT and Autonomous robots                                     | ++              | +++                     | +++          | +++                     |
| Procurement and inventory management                          | +               | +++                     | ++           | +++                     |

For a specific process, the proposed practical work contains guidelines that enable students to merge deeper into a relevant subject as their grade progresses. Thus, for their understanding, it is important that students have the suitable background knowledge of the main disciplines, an appropriate knowledge of the basic principles of technical analysis of mechatronic, robotic, and connected systems based on the generated competencies and their degrees of deepening to make learning paths throughout the considered learning grade. The result of this work is the last version of the guidelines, specially developed for the CPS platform.

### ***Pedagogical implementation through a collaborative model***

Although the work described in this manuscript focuses on system design, it is essential to consider all phases and requirements of the product life cycle. The different types of product integration presented below are also a source of organizational complexity. They require a high level of collaboration, which not only leads to organizational complexity, but also to the diversity of the domains involved. Thus, a multi-disciplinary collaborative integrated system for mechatronics training was designed and implemented in an evolving professional environment described below in Figure 2.

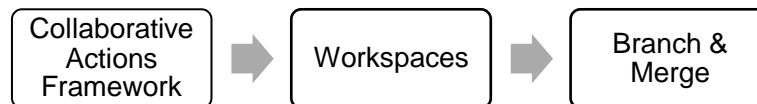


Figure 2. Agile method for multidisciplinary collaborative design

The model improve collaboration between the various disciplines by reducing the existing compartmentalization between the players involved. It is a direct response to the problem of the correlation between lack of collaboration and the resulting low level of product integration. As a result, laboratory equipment is based on an integrated approach, i.e., sequential step-by-step development and a multi-level approach to differentiating educational levels. We have

taken care to balance the criteria of duality, versatility, and adaptability of the chain through modular cells that can be arranged according to the objective and level of depth of the activity. To perform this task, the teaching-learning approach (Mäkiö-Marusik et al., 2019) is adopted as a flexible and dynamic system open to the changing demands of the world of work and the specialized and/or multi-disciplinary trends all within the framework of the CBL approach performed by the project-based learning model (Meng et al., 2023) through an integrated curriculum approach (Tuselim et al., 2020). The agile method for multidisciplinary collaborative design aims to break down the barriers between disciplines by making design activities more agile, information propagation simpler and understanding of expertise phenomena clearer.

## **CASE STUDY**

### ***Collaborative learning path***

#### *Action 1: Collaborative action framework (CDIO Standard 5)*

The collaborative actions set up during the action request creation phase are (a) Specification of a mechatronic system requiring knowledge of the disciplines of robotics, pneumatics, electrical engineering, supervision and automation (b) Sequential design of system behaviour (c) IoT data collection and analysis. The orientation phase of this approach is based on the creation of groups of students supervised by multi-disciplinary teachers who assign them different actions to achieve different learning goals. Students and expert teachers' study, discuss and, if necessary, modify the action requests to draw up precise specifications. The implementation phase is based on group work and weekly meetings to present the progress of the work and assess the learning outcomes according to their degree of depth. This step calls on the second notion of this agile method, which is the workspace to reference every modification made and every data updated. The close-out phase is defined by the completion of tests on the machines and the start-up and communication of the processes in consideration. Validation of collaborative actions considers all assessments made during implementation of the requested actions, which are weighted according to the learning outcome and its level of depth. Indeed, during the implementation stage, if validation is not achieved, the action is transferred back to the student group, with recommendations. Completion of this action is marked by passing the tests.

#### *Action 2: Collaborative action framework (CDIO Standards 6)*

In a workspace, every action in every discipline is referenced. This space makes available the work of each group and provides visibility on the different strategies deployed to solve an engineering problem. It also creates traceability and facilitates the acquisition of available and necessary data for any team involved in the workflow. Peer evaluation is thus possible to bless students to benefit from the knowledge and vision of others on their work and thus learn with a different approach.

#### *Action 3: Branch and merge (CDIO Standard 7)*

The branch creation and merge operation are essentially based on the parallel contribution of several participants in the same share for integrated learning. This enables us to achieve better results in less time. This concept is ensured by the synchronous work of different parties and disciplines making the data available. There is no longer a privileged contact for a better design or for a possible modification. An action can be refined and improved. Interactions between



engineering activities or between disciplines could thus be facilitated. Thus, students can analyze productions, considering the economic and environmental sustainability aspects of the solutions established as part of the same learning experience.

### ***Preliminary survey and discussion***

To analyze feedback on post-installation pedagogical activities, a qualitative method was used. This involved direct or participative observations (professional or formative situations), explanatory or comprehensive interviews with learners or their tutors, and documentary analysis of written traces (learners' productions). Throughout our model development, we were able to observe that decision-making in a design project is facilitated by more frequent and regular feedback of precise operational information. This information may concern tasks in progress, requirements considered, difficulties encountered by the various design teams or a certification result. We also noted the traceability between the changes made to the system definition data and the decisions taken throughout the development project. The aim of this traceability is not only to improve design project management but also to be able to draw lessons from design projects to better anticipate future projects. Thus, a pilot class of 30 students was chosen to evaluate the cognitive integration of the platform, throughout the pedagogical process around specific workshops. The predefined learning elements were supported by milestones for groups of students. Through the CPS implementation the student acquires a comprehensive understanding not only of the core disciplines, but also of related disciplines. The student's interest increases as clear interdisciplinary links emerge. In addition to analyzing the student's motivation, a study of the skills acquired in terms of employability was carried out. The main employability skills acquired were teamwork, problem identification, research, time management, organization, leadership, analysis, entrepreneurship, innovation, and project management. Skills such as negotiation, persuasion, flexibility, and proactivity did not score well, which is common among students adapting to the university environment. Moreover, a Tia Portal Siemens certification process was also set up during the same year of implementation, with a larger sample covering the entire graduating classes. 63% of students wished to take the certification, relying on the learning outcomes achieved in the dedicated workshops. The success rate was 85% for Siemens TIA portal "Advanced" certification. The next step will be to set up an appropriate scientific method for student assessment, to generate results from the training process and program content, in line with norms 11 and 12 of the CDIO Standards.

## **CONCLUSION**

The modular cyber-physics technology platform was adapted to work situations and fed by real industrial projects as part of a skills-based approach. The pedagogical model implemented enabled students to develop skills in the field of electromechanical systems. Introducing this practice into the educational process gave students the opportunity to apply theoretical knowledge in a practical environment, namely the development of CPS. By another hand, application of CDIO Standards in the teaching of CPS was a solid example of the practical implementation of international engineering training standards within electromechanical department workshops. The scientific analysis of educational situations as part of the professionalization of trainee teachers cannot be limited to the study of results at the level of immediate knowledge alone; it must be carried out on an ongoing basis at the various levels and phases of the study, in accordance with Standard 10 of the CDIO framework. It is essential to consider the various cognitive, cultural, and economic aspects involved in the search for relevant interpretations of the observations made.

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# CDIO IMPLEMENTATION FOR ESPRIT UNIVERSITY STUDENTS DURING INTEGRATION WEEK

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## ABSTRACT

Since 2012 Esprit (Private Engineering and Technology School) focuses on training directly operational engineers through an innovative pedagogical approach in particular project/problem-based learning (PBL). Esprit first-year students are often willing to embrace challenges, but these may not always align with what teachers have in mind given that they were, throughout the entire curriculum, as passive receivers. To better support first-year students and foster knowledge acquisition, performance, engagement, collaboration and the overall positive learning experience, Esprit organizes a yearly integration week named PBL0 from all specialties IT, electro-mechanical, civil engineering. It is also intended to facilitate students' transition to university life by combining fun collaborative activities and assisting them in settling into their new surroundings. In this context, the integration week has been designed to incorporate sustainability aspects in a project aligned with CDIO standards 3, 5 and 8 as guidelines and has been formulated to include active learning in its many forms, such as project/problem-based learning, case studies, small group discussions and oral presentations. This research paper will expose the designed scenario of the integration week and the various actions that students should take to gain the required knowledge. It starts with brainstorming to promote student recognition, followed by a design phase, which focuses on translating conceptual ideas into a concrete plan. This includes creating prototypes and selecting appropriate technologies. The third stage involves implementation, focusing on developing the desired output. The project concludes with an evaluation, where the best projects are chosen based on a criteria grid.

In this work, we will go over each stage of the project in detail and provide results discussion in light of how the integration week was perceived by the students.

## KEYWORDS

Project-based learning, first-year engineering, sustainability, CDIO standards 3, 5, 8.

## INTRODUCTION

First-year students must be shaped at an early stage to fit their profile by the time they graduate. Thus, it is essential to concentrate on learning goals related to attitudes, teamwork, leadership, and communication abilities. However, it's not easy to learn these skills, especially in the context of engineering training.

Welcome days at universities is an event organized specifically for new students at the beginning of the academic year. This event aims to introduce incoming students to the university environment, its resources, and the campus community.

It typically includes a series of activities and sessions designed to assist new students acclimate to their new academic environment and to be familiar with the pedagogical concept adopted by their university.

In this context and for 12 years Esprit (Private Higher School of Engineering and Technology) organizes an integration week for first-year students across all specialties computer science electromechanics and civil engineering, known as PBL0 "Problem Based Learning 0", this week serves as an introduction to the active learning approach adopted by our university. PBL 0 is a teaching unit that forms part of the study plan, with a coefficient equivalent to 1 ECTS (the European Credit Transfer and Accumulation System adopted by Esprit). (European Commission,2015).

For the integration week of 23-24 academic year, Esprit received 1840 students, who were divided into 300 multidisciplinary teams by committee members before the beginning of the event, working on a specific topic and supervised by 75 tutors from various specialities. At the end of this period, three teams will be selected as winners.

Various constraints confront these challenges, including: the large number of students, the variety of specialities among students and teachers, and the status of being first-year learners.

In order to deal with these limitations, it is necessary to respond to the following inquiries:

- What would be the recommended approach to better support first-year students and prepare them for active learning?
- Which subject best suits the diverse skill sets of both instructors and students?

Esprit is promoting advanced engineering education in Tunisia and has gained international recognition through its membership of the CDIO initiative founded by MIT (Massachusetts Institute of Technology).

A particular focus on engineering education is to enable engineers to develop new techniques and technologies in an era of technology, information, and inventive economies. A complex approach for developing specialists who can manage a system, product, service, or process through its whole lifecycle is outlined in the CDIO International Standards. Conceiving, designing, implementing, and operating engineering activities are a context in which the framework places a strong emphasis on engineering basics. The term CDIO is an acronym for all four phases. (Crawley et al., 2007).

The CDIO initiative is based on four phases namely:

- Conceive phase: Defining customer needs; considering technology, enterprise strategy, and regulations; developing concepts, techniques and business plans.

- Design phase: Creating the design; plans, drawings, and algorithms that describe what will be implemented.
- Implement phase: Transforming the design into the product, including manufacturing, coding, testing and validation.
- Operating phase: Using the implemented product to deliver the intended value, including maintaining, evolving and retiring the system.

Since 2013, Esprit provides a pilot program integrating CDIO concepts into project-based learning to manage the integration week through conceive, design, implement and operate phases.

In order to ensure that the highest standards of education are maintained, the CDIO Initiative has defined twelve standards that every program established under the CDIO syllabus must meet. (Malmqvist et al.,2019)

In this study we focus on Standard 5 “Design-Implement Experiences”, standard 8 “Active Learning”, (Brodeur & Crawley, 2009) and the current version of the Syllabus 3.0 “the new optional CDIO Standard for Sustainable Development” (Malmqvist et al.,2022) to illustrate the way in which instructors provide students with the skills of active learning, problem-analysis and problem solving, teamwork and communication. (Malmqvist et al.,2020)

In this case study, we will describe our strategy and show how students can progress from problem identification to the development of solution using CDIO approach.

This paper starts by giving an overview of the methodology implemented followed by a detailed explanation of how each phase of CDIO is applied in our case. It concludes with an analysis of results, considering the students' perceptions of the integration week.

## **RELATED WORK AND BACKGROUND**

All of us are the result of traditional pedagogy. We acquired knowledge through attending lectures and completing traditional written assessments. Student and instructor training is necessary for changing education reform to innovative pedagogy focused on real-world issues that relate to the working world. (Caroline Verzat,2009)

We draw inspiration from the fruitful experiences of our Belgian colleagues at Louvain-la-Neuve, who have been using active learning strategies with their students. (D. Ducarme and B. Raucent,2011)

Since 2012, Esprit has organized the “PBL0” week at the start of the academic year, dedicated to raising awareness of active learning among first-year students. Given that each year a different topic is set to be carried out, students are grouped into teams to solve the problem.(Kaouther.L et al.,2016)

Due to the Covid-19 pandemic, we had to move towards creating online content. This included creating lecture videos and developing different skills using online Learning Management Systems (LMS) for communicating with students, presenting the schedule for the week as well as the content of each slot, moderating discussion forums and holding assessments.

## METHODOLOGY IMPLEMENTATION

To ensure that all students complete their projects on schedule, it is necessary for the project to be refined into concrete steps and the CDIO approach is selected.

As shown in Figure 1 the designed scenario of the integration week “PBL0”, spread over 4 days, follows four steps as they progressed from problem identification to solution development.

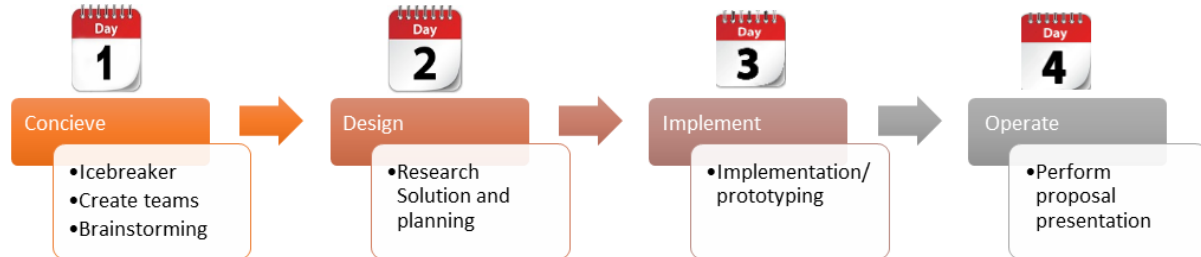


Figure 1. PBL0 Using CDIO.

### **Conceive**

The conceive phase takes place on the first day of the integration week. After the welcome ceremony given by the Esprit directors, students and tutors join their respective classrooms, according to an order previously communicated by the PBL0 organising committee.

The integration week starts with an icebreaker activity with the aim of facilitating interaction and communication between participants, building a positive classroom atmosphere and creating a positive learning experience.

As groupwork is a vital aspect of project-based learning, fostering students' confidence in handling meaningful challenges, students are divided into multidisciplinary groups, with 6 to 8 members per team.

The goal of multidisciplinary Project-Based Learning (PBL) is to foster collaboration and integration of knowledge from various disciplines. By working in multidisciplinary teams, students bring diverse perspectives, skills, and expertise to solve complex, real-world problems. (Buck Institute of Education, 2015).

Students were engaged to undertake a real-life project that aligns with the student's different specialities and focuses on Sustainable Development Goals (SDGs) 3 "Health and Well-being" and 4 "Quality Education". (The United Nations,2023)

The project, titled "University Life Project," aims to create a 3D model of university life to shape a well-rounded and open-minded student who receives a quality education and becomes a responsible citizen.

At the end of the first tutored session, the instructor presents and explains the challenge for the week, the progress of the first phase and the assignments that must be achieved during the asynchronous part of the conceive phase, which are already configured in the course space.

In this phase, teams need to understand the current context of the problem and generate project ideas. For that, we suggest making internal research to identify the existing solutions. To ensure the success of this phase, we have offered students a range of activities including quizzes, videos, and a discussion forum within the course space.

Once the first day is over, all the teams are invited to submit a theoretical study on the course space.

In Table 1 is the conceive phase undertaken during the first day of integration week.

Table 1. Conceive Phase

| Student's activity                                                    | Instructor activity                                      | Product           | Resources                                         | Learned skills                                 |
|-----------------------------------------------------------------------|----------------------------------------------------------|-------------------|---------------------------------------------------|------------------------------------------------|
| Research on project ideas<br>Combining ideas<br>Generate project idea | Explain the problem.<br>Guide students in their research | Theoretical study | Quiz, videos and questions related to the subject | Critical thinking<br>Communication<br>Teamwork |

### **Design**

The design phase focuses on translating conceptual ideas into a concrete plan.

Once the idea generation has taken place, the students are led to research possible alternatives in order to evaluate, compare and choose the best one.

Before proceeding with the design of the models, the tutors must make sure that the suggested solution satisfies the requirements of the topic in question before moving further with the model's creation and providing the required tools.

Following this step, students move on to the theoretical study of the selected solution based on planned activities that includes general design guidelines.

In order to select appropriate tools and build the solution prototype, students split up their work such that each person is in charge of a single assignment.

To assist students, throughout the entire development process, instructors are available for consultation.

When design flexibility and group work are combined, a decentralised learning environment is produced where groups may receive feedback and direction related to their theoretical knowledge design.

Based on instructor feedback, students can iterate on their assumptions and their design decisions before starting to create their scale models.

In Table 2 is the design step undertaken during the second day of the integration week.



Table 2. Design Phase

| Student's activity                                  | Instructor activity                         | Product                   | Resources      | Learned skills                                                      |
|-----------------------------------------------------|---------------------------------------------|---------------------------|----------------|---------------------------------------------------------------------|
| Identifying necessary tools<br>Generate design plan | Discuss and validate the theoretical study. | Provide a technical study | Software tools | Technical skills<br>Communication<br>Teamwork<br>Project management |

### **Implement**

The implement phase consists of creating final products. After finalising the product concept, each team is required to build a 3D model in line with the conceptual study already completed. Given that they work on a sustainable project they use recyclable materials such as plastic bottles, cans, cardboard, etc. to create the solution model. As shown in Figure 2, it's quite simply extraordinary for students and tutors to see such innovative and creative projects.

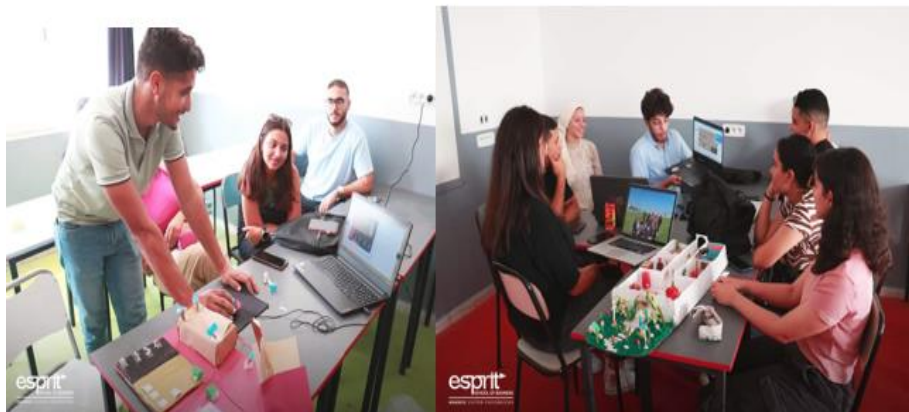


Figure 2. Students' Prototypes

In Table 3 is the implement step undertaken during the third day of the integration week.

Table 3. Implement Phase

| Student's activity      | Instructor activity   | Product           | Resources                              | Learned skills                          |
|-------------------------|-----------------------|-------------------|----------------------------------------|-----------------------------------------|
| Implementation of ideas | Supervise the process | 3D solution model | recyclable materials<br>Software tools | Creative & technical skills<br>Teamwork |

### **Operate**

The operate phase takes place at the end of the week, this is the most rewarding stage as all the projects are already working and ready for viewing and assessment. At this level, teams need to present their project to their coach, their colleagues, guests and the directors of Esprit. For that, they need to prepare a pitch and a presentation that explains the idea and highlights the efforts made by the entire team. As PBL 0 is a module in the first-year programme, it must be graded. During the "operate" phase, each team must present its

solution. The tutor validates their work by completing a criterion grid assessing both the scientific content and the oral presentation. For the scientific content, four assessment criteria were proposed: the importance of the problem and its impact, the choice of the suggested solution, and the product's quality. As for the oral presentation, the teams will be assessed on the quality of their oral presentation and their argumentation.

The integration week concludes with a ceremony where three best projects are chosen based on a criteria grid considering the project's creativity and originality.

In Table 4 is the operate step undertaken during the last day of the integration week.

Table 4. Operate Phase

| Student's activity            | Instructor activity                                  | Product                                     | Resources      | Learned skills                                                               |
|-------------------------------|------------------------------------------------------|---------------------------------------------|----------------|------------------------------------------------------------------------------|
| Perform proposal presentation | Project evaluation<br>Selection of the best projects | 3D solution's model<br>Presentation support | A scale model. | Critical & thinking skills.<br>Communication<br>Technical skills<br>Teamwork |

**RESULTS AND ANALYSIS**

In this section, we demonstrate the significance of using the CDIO approach to introduce the project-based learning to first-year engineering students through their final marks and a survey. The breakdown of students' final marks is shown in Figure 3.

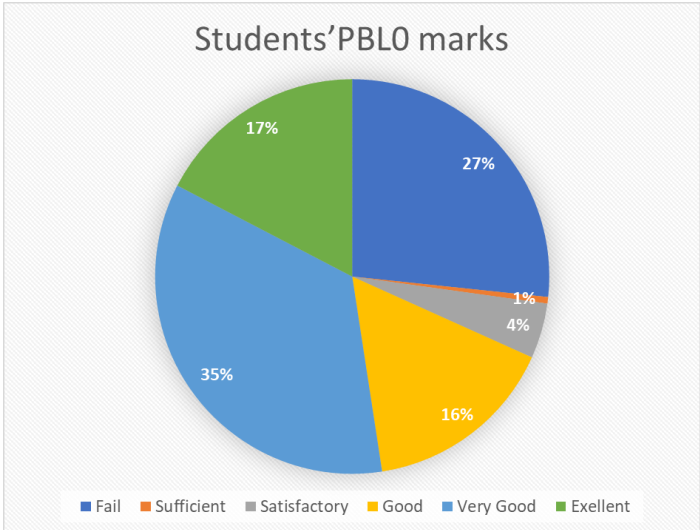


Figure 3. Students' PBL 0 Marks

We note that 74% of students successfully completed PBL0, with 68% achieving good to excellent grades. Indeed, most of the students who did not validate PBL0 were absent during the integration week.

The survey was performed at the end of the first semester of the current academic year 23-24. It used a series of questions qualified by the 3-point Likert scale.

In this section, results from 432 responses received are presented and followed by discussion, pointing out the strengths and weaknesses of using CDIO in a project-based learning during the integration week. Our attention focuses on the dimensions related to:

1. Students' PBL0 perceptions,
2. Achieving project's goals through CDIO approach,
3. Preparing students for active learning through CDIO approach,
4. Students' learned skills.

The dimension 1 "Students' PBL0 perceptions" intends to evaluate the perceptions of students related to the integration week in general and the results of the survey are presented in Figure 4, showing that among 432 students, 93% were satisfied, while 7% were not.

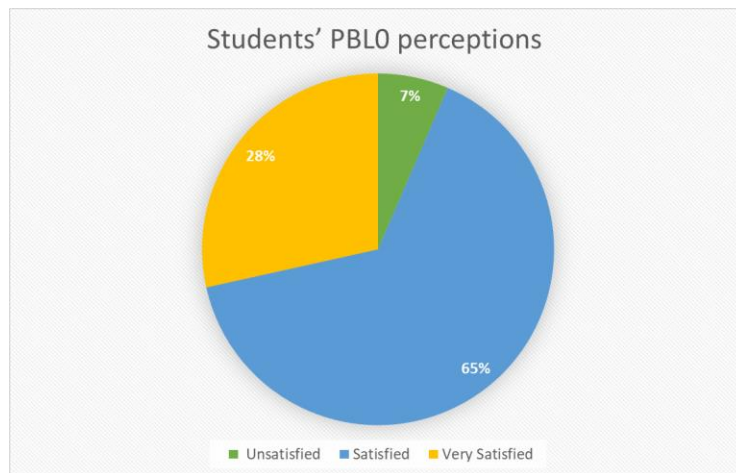


Figure 4. Students' PBL0 Perceptions

The dimension 2 analysed is related to "Achieving project's goals through CDIO approach". Figure 5 shows that 92% of students attest that the four phases of the CDIO allowed them to accomplish their project's goals, while 7% weren't satisfied with the previously outlined process.

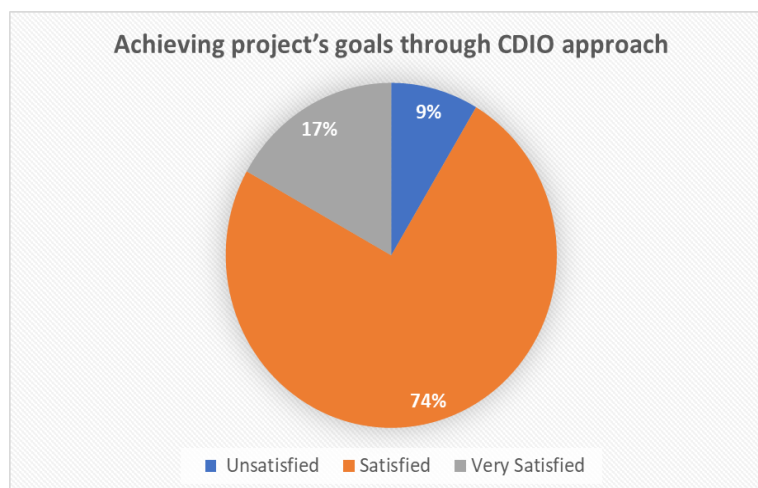


Figure 5. Achieving Project's Goals Through CDIO Approach

Another analysed dimension pertains to “Preparing students for active learning through CDIO approach”. Figure 6 shows that 85% of students thought that using the CDIO four phases in the integration week, enabled them to familiarise themselves with the project-based approach applied in the first semester, while 15% believe that it did not.

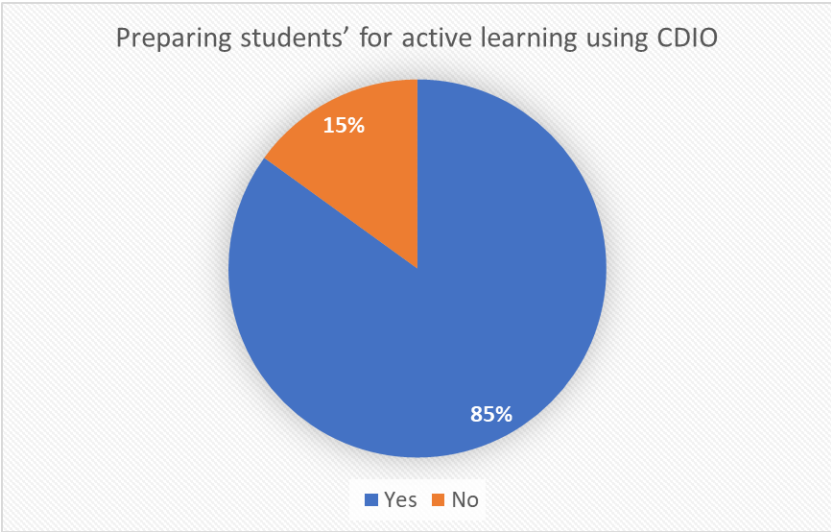


Figure 6. Preparing Students For Active Learning Through CDIO Approach

As seen in Figure 7 which analyses the last dimension "Students' learned skills".

Students highlights that the PBL0 contributes strongly to the development of skills that are important for pursuing the curriculum of engineering students, such as team-working, communication, project management and thinking & critical skills.

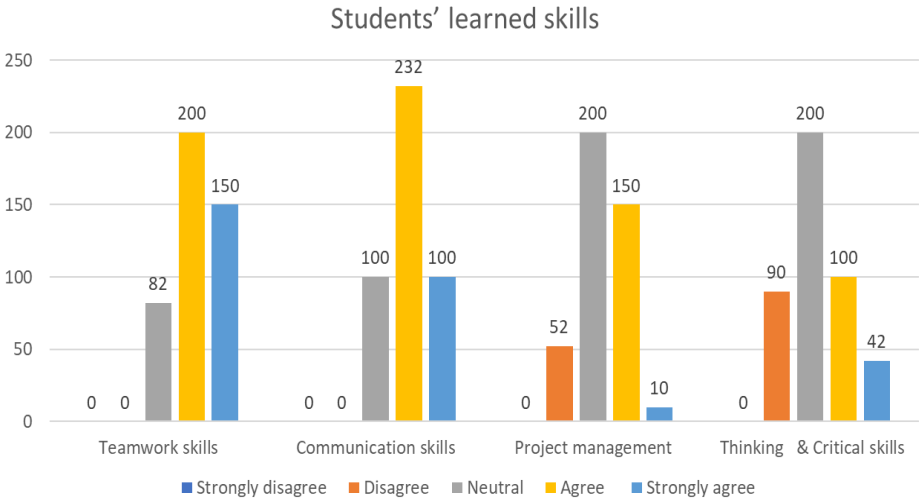


Figure 7. Students' Learned Skills

Considering the above, it is clear that the majority of students had a positive overall experience and believed that the integration week using the CDIO process had improved their grasp of the PBL approach. However, a minority of students seem to be dissatisfied with the integration week. This attitude can eventually be explained by the fact that four days are not enough to

learn about the active approach. Another potential issue that may be contributing to the discontent among students is the disparity in their backgrounds especially as it was their first steps to tackle new academic challenges unlike to what they had previously encountered. Furthermore, teamwork could also be seen as an obstacle for some students who are used to working on their own.

## **RECOMMENDATIONS**

Overall, and according to feedback from teachers during the retrospective meetings held at the end of the integration week, the model works well. It is both an opportunity for students to learn in an engaging way and to gain knowledge through experience.

To offer a more effective experience, it could be required to implement specific adjustments to the process:

### ***Synthesis***

Before closing the event, it is essential to summarise the knowledge acquired by the students on active learning during the integration week via a question-and-answer session, highlighting the role of adapting the CDIO approach in the process.

### ***Information points in non-tutored sessions***

Students appreciate having areas where they can ask questions outside the classroom. In future iterations we intend to set up information points attended by tutors to provide students with better guidance and meet their needs in non-tutored sessions.

## **CONCLUSION**

This paper highlights how the CDIO approach was successfully conducted the integration week intended for first-year engineering students under the guidance of instructors that are specialists in different areas.

Both teachers and students may find it challenging to switch from traditional teaching and learning methods to an active learning atmosphere. To guarantee this transition throughout the integration week, the CDIO strategy has been applied to the above case.

According to the concept of Standard 3, 5 and 8, we found that embedding CDIO into the integration week produced positive results as revealed by students' performance in creating innovative projects, improving self-learning, problem-solving, communication skills, team-working, and knowledge acquisition.

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# MOTION CONTROL AND COORDINATION PLATFORM FOR MOBILE ROBOTS

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## **ABSTRACT**

The training of a mechatronics engineer requires the application of a variety of skills in different projects. The "Robotics Project" optional module is aimed at 5th year Electromechanics students, who will be able to read up on a wide range of subjects such as embedded systems, sampled systems, automatics, robotics, machine control, programming and IOT, all of which form part of the training curriculum for Mechatronics engineers (standards 1,2,3). The implementation of a servo-controlled mobile platform highlights the different variants listed in a pedagogical approach that links these different modules in a single project. This project provides engineering students with a global vision of their field, putting into practice a range of knowledge that students may not see in the modules in question or in previously developed projects. This generalization of practices touches on knowledge encompassing several modules. This approach takes the form of a workshop to review the theoretical notions already studied and link them up with the project (standards 4). The first workshops focus on embedded systems and machine control, using microcontroller boards to read encoders and set the appropriate command. Then, the interpretation of velocity is done through the choice of an echo frequency (standard 5). To finalize the work, we are connecting each robot so that it can send back its position wirelessly via an IOT communication protocol (standards 6,7,8). A second version of the project is developed this year with a different robot model. To achieve more satisfactory results, we have introduced more guided sessions to focus more closely on the desired learning outcomes through skills-based learning scenarios. The results of this second approach are still in progress. The whole platform is used as a validation tool for a group robotics platform to test different group motion algorithms. A positive results of student survey highlight the crucial role of practical projects in preparing mechatronics engineers for the dynamic professional landscape, with continuous improvements ensuring the module's sustained efficiency.

## **KEYWORDS**

Robotics, Embedded Systems, IoT, Integrated Learning, Syllabus: 1, 4, Standards: 1, 2, 3, 5, 6, 7, 8.

## INTRODUCTION

Mobile robotics has become an integral component of mechatronics engineering, bridging theoretical knowledge with practical applications. In recent years, the field has witnessed significant advancements driven by the convergence of embedded systems, automatics, and the Internet of Things (IoT) (Seeja, Reddy, Kumar & Mounika, 2021). As educational institutions adapt their curricula to meet the demands of a rapidly evolving technological landscape, integrating a dedicated robotics module becomes imperative.

The "Robotics Project" optional module, tailored for fifth year electromechanics students, aims to provide a hands-on experience that consolidates diverse knowledge gained throughout their studies. This initiative aligns with the evolving landscape of mechatronics education, where interdisciplinary skills play a pivotal role (Jenabi, Shahri & Beyad, 2016). The choice of functionalities in the project is rooted in the emphasis on skills acquired in previous modules. As mobile robotics encompasses a wide spectrum of engineering domains, the project serves as a culmination of theoretical concepts from embedded systems, automation, electronics, and IoT (Sackey & Bester, 2016). This amalgamation of skills ensures that students are not only well-versed in individual disciplines but also capable of synthesizing their knowledge for practical implementation.

The significance of introducing a robotics module towards the culmination of the engineering curriculum is underscored by the need for students to connect theoretical knowledge with real-world applications (Suarez, García-Costa, Perez, López-Iñesta, Grimaldo & Torres, 2023). Robotics projects facilitate a holistic understanding of mechatronics, fostering problem-solving abilities and critical thinking. The project unfolds in a series of workshops that cover fundamental aspects of motion control, starting with open-loop DC motor control and progressing to complex tasks such as trajectory planning and odometry. The design of the first robot model incorporates microcontroller-based boards aligned with IoT communication protocols and specifications similar to those encountered in 'Embedded Electronics' and 'Advanced Embedded Electronics' modules (Romeo, Petitti, Marani & Milella, 2020). In response to initial results and student feedback, a second model is introduced, refining the motorization, and enhancing autonomy during tests. This iterative approach aligns with contemporary engineering practices, where constant improvement and adaptation are key to addressing emerging challenges (Wei, 2016). As mobile robotics continues to play a pivotal role in engineering education, the integration of practical projects like the one presented herein ensures that graduates are well-prepared for the dynamic and interdisciplinary nature of the modern workplace (Baranowski, Kucharska, Kawalec, Malinowski & Piwowarski, 2023). Daniela & Lytras (2018) worked on conceptual model of technology enhanced learning development to lead the student from the lower level of thinking, characterized by simple digital skills, to a higher level of thinking, which is characterized by the design of new knowledge and the creation of new products. On another hand, the CDIO community is addressing this research theme by developing robotics teaching platforms with the help of the CDIO initiative, enabling students to apply their existing knowledge to real-life problems and situations (De Carvalho, 2016; Sánchez, Morales, Londoño, Sánchez & López, 2017; Daniela, 2019; Bravo, Hurtado & González, 2020). Through our work, we aim to move forward and guide sessions to focus more closely on desired learning outcomes through competency-based learning scenarios.

In fact, this paper is structured as follows: the first section describes the initial approach, which involves conceiving a standardized robot model. The section covers session proceedings, achievements, and limitations of this approach in detail. The subsequent section discusses the



second approach, titled "A new training approach updating the robot ", revealing the design of the robot, as well as the updates and the innovations in learning techniques. Furthermore, we present and discuss the obtained results endorsed by simulations and achievements of studied robots, proposing specific additional requirements. Additionally, the results of a student survey are outlined, ensuring the continuous improvement of the Robotics Project module. Finally, we conclude the main work and provide insights into few perspectives.

## "ROBOTICS PROJECT" IMPLEMENTATION

Firstly, the functionalities of discussed optional module are determined and chosen by the skills emphasized in the diverse modules studied previously. The Table 1 summarizes the skills and the functions expected of the robot designed. This work consists of the implementation of two solutions. The first conceived robot presents standardized model for effective teaching across various workshops, minimizing the need for familiarity and maximizing learning outcomes tailored to each workshop. The second approach involves enhancing the designed robot with electronic upgrades to boost accuracy and autonomy, with detailed insights into the learning outcomes for this solution.

Table 17. Skills and functions expected of designed robot

| Module Taught                 | Parts to be highlighted                                                          | Robot functionalities                                                                                                                                                                                                              |
|-------------------------------|----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Embedded electronics          | GPIO, ADC, Timer, PWM                                                            | <ul style="list-style-type: none"> <li>▪ Reading encoder outputs</li> <li>▪ Reading a potentiometer to vary a control parameter</li> </ul>                                                                                         |
| Advanced Embedded Electronics | Internal Interrupt, External Interrupt, Hardware Debugging<br>UART communication | <ul style="list-style-type: none"> <li>▪ Calculate speed at each Internal Interruption</li> <li>▪ Calculate position for each external interrupt</li> <li>▪ Monitor parameter evolution in real time Hardware debugging</li> </ul> |
| Machine control               | DC motor control                                                                 | <ul style="list-style-type: none"> <li>▪ Varying the speed of a DC motor</li> </ul>                                                                                                                                                |
| Automatic                     | PID control                                                                      | <ul style="list-style-type: none"> <li>▪ Design a speed control algorithm for a motor</li> </ul>                                                                                                                                   |
| Robotics                      | Behavioral modeling                                                              | <ul style="list-style-type: none"> <li>▪ Modeling robot motion</li> </ul>                                                                                                                                                          |
| IOT                           | Setting up connected nodes via the MQTT protocol                                 | <ul style="list-style-type: none"> <li>▪ Return robot coordinates via MQTT protocol</li> </ul>                                                                                                                                     |

To follow-up pedagogical activities, a schedule of activities is represented in Table 2. The schedule is strictly controlled by the module manager under the supervision of the teacher in charge of teaching. During the monitoring of the implementation process, the head of department invited the teacher in charge and the module manager, where appropriate, to analyze incoming methods and principles to correlate them with the competencies-based learning method already in place and adjust them if necessary to the targeted skills. Indeed, the curriculum is designed with mutually supporting disciplinary courses (standards 2) with a regular review and revision of the program learning outcomes (Standard 3). This enabled the teachers to stay focused on the pedagogical objectives, and the students to properly converge

and merge their skills and knowledge of mobile robotics development in an interdisciplinary and physical environment around problem-solving activities through active and experiential learning methods (Standard 8).

Table 2. Schedule of Activities

| DATE                                                | ACTIVITY                                                                        |
|-----------------------------------------------------|---------------------------------------------------------------------------------|
| From 13 to end of September                         | Submission of the requirements<br>The system flow design                        |
| 1 <sup>st</sup> Week of October                     | The architecture of the system                                                  |
| 2 <sup>nd</sup> Week of October                     | Partial Checking of Equipment's, Software systems, and manuscript               |
| 3 <sup>rd</sup> and 4 <sup>th</sup> Week of October | Create initial system design.<br>Follow-up checking / Presentation              |
| 1 <sup>st</sup> Week of November                    | Final checking of Video Tutorial, System Manual, Robotic system, and manuscript |
| 2 <sup>nd</sup> Week of November                    | Final submission of all the requirements.<br>Lacking requirements               |

## FIRST APPROACH: STANDARDIZED ROBOT MODEL

An initial model is developed for this purpose, in collaboration with other disciplines, to guarantee the functionality of all the modules. The first objective was to build a standard model to ensure a didactic model not only for this module but also for a multitude of workshops to provide the framework for robotics engineering practices (Standard 4) for different levels and disciplines including multiple design-implement experiences (Standard 5). The aim of this approach is to minimize familiarization with the model in order to maximize learning by varying the learning outcomes to suit the workshop in question in a physical learning environment (Standard 6). The aim is to standardize the equipment to facilitate maintenance and reduce the time required to assimilate the different parts of the robot, while retaining functionality adapted to each level and specialisation. Each level in the electromechanical cycle will study a series of functions to harness the robot's potential in the 5<sup>th</sup> year.

### *First model design*

A preliminary two-wheel drive model has been designed using two microcontroller-based boards. The first board is dedicated to robot control, while the second focuses on communication. This type of motorization is designed for robot vacuum cleaners. We felt that this kind of device would be an additional asset to immerse it further into the field of service robotics (Mugure, 2019). The Figure 1 illustrates the design of the first robot implemented.

One of the advantages of such a solution is to ensure the most compact motorization possible from an industrial environment. Careful consideration was given to align these boards with those utilized in IoT modules for the communication board, and closely mirror the specifications of the 'Embedded Electronics' and 'Advanced Embedded Electronics' modules for the control board. The development software platforms were also selected to closely match the specifications of these modules. The design and implementation of this model occurred independently of coaching sessions, with mechanical design not being a primary focus to align with the pedagogical objectives of other modules.

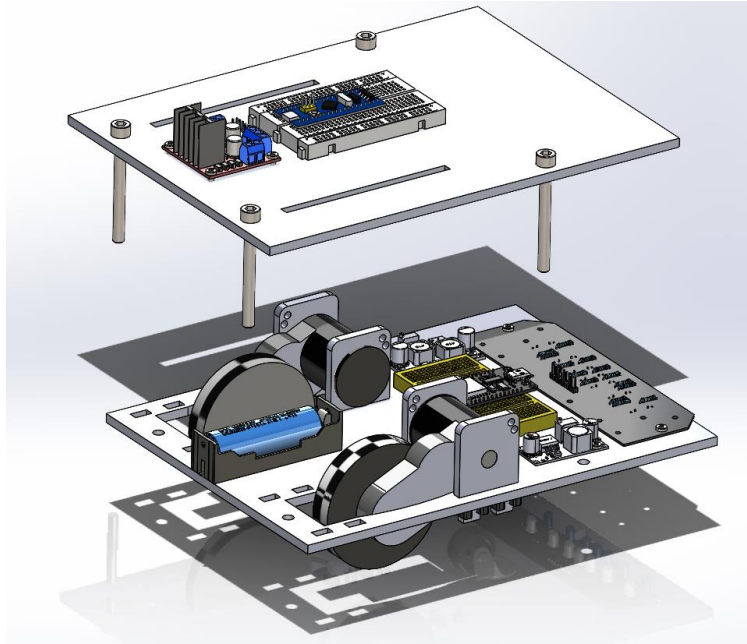


Figure 20. Design of the first robot model

The first step of the workshop is to control the DC motors in open loop. Generating PWM signals via the control board and varying the motor speeds is established. The PWM signals is controlled via the Timer configuration. Students are encouraged to choose a PWM signal frequency according to electrical and mechanical properties, and to determine its impact on motor torque and speed. The next phase involves reading the value from a potentiometer and adjusting it for control. Subsequently, the workshop will cover reading encoder values from manual wheel movement. Using GPIO and external interrupt for reading encoder values and determining wheel position is an integral part of this section. The determination of velocity is the next phase in the training. This phase involves using internal timer interrupt. Students are required to set a sufficient sampling frequency to ensure smooth reading of values, considering the control loop. The control part will connect the PWM motors control and speed reading in its regulation phase. This stage is researched and implemented to find the appropriate PID coefficients. Testing, interpretation, and validation as the coefficients are modified gradually develop critical thinking and analytical skills in engineering students. The subsequent phase includes trajectory calculation and planning. Students need to grasp the process of transforming the task of trajectory planning into a sequence of motors setpoints through the creation of a model for robot's displacement. In addition, the simulation tools are employed to verify the behavior. The following part will focus on robot geolocation through odometry. This geolocation will serve to relay the robot's position and orientation to the network to correct the trajectory. Data transfer from the robot is occurred from the control board to the communication board via the UART protocol.

### ***Session proceedings***

The initial sessions were conducted in the form of workshops. The first workshop consists of a practical scenario of assembling and wiring the robots. Students were familiar with the equipment used, as most of them had already used it in other projects. The use of a board similar to the one used in the Laboratory work facilitated learning and accelerated progress. In

addition, the use of laboratory work resources ensured the deepening of knowledge and skills acquired in previous sessions were further developed.

In this regard, the inclusion of the "PWM Signal" and "ADC" laboratory works in motor control streamlined the workshop. The "EXTI" and "Timer" practical works facilitated the assimilation of encoder reading. The workshop, structured in the form of practical exercises, concluded with the implementation of the PID control structure. The remaining sessions took the form of supervision, allowing students the critical spirit to test and validate their own work. The teacher's intervention occurred to validate a phase or to guide the group in their project development process.

### ***Approach results and limitations***

Most of students grasped the purpose of the topic with an understanding of the robot's functionalities. The variety of tools used in the development of the second part (supervision part) fostered an exchange among the groups to arrive at a reliable solution leading to the acquisition of disciplinary knowledge, as well as initiative-taking behavior and teamwork (Standard 7). Nevertheless, the time spent on research and solution development is substantial and is conflicted with the finalization of the connection and odometry phases.

The first prototype limited learning in the level of robot autonomy. The limited autonomy created dead times during recharging. Students encountered issues with connections, resulting in errors during the assembly and disassembly of the cell for recharging, consequently causing damage to the equipment used. Single-channel encoders constrained the work involved in regulation tasks. Mounting the electronic boards on two levels restricted accessibility and increased the assembly's complexity. All the aforementioned shortcomings were confirmed during various discussions with students. The students' feedback and technical suggestions will be taken into consideration in the development of the second prototype.

## **SECOND APPROACH: A NEW TRAINING APPROACH UPDATING THE ROBOT**

The necessity for a new model emerged from several issues identified with the initial model. The electronic circuits are upgraded while preserving the same educational goals. This update is conducted autonomously from other modules.

### ***Second model design***

The concept of collaborative work to create a unified robot is redefined, opting for a functional model for each module and subsequently seeking a robot that integrates the entirety, rather than designing it from scratch initially. The outcomes of one project will be discussed in another article. The motorization has been changed to achieve greater precision in control strategy. The battery is modified to ensure more autonomy during tests. In this new approach, students are empowered to determine the robot's design, including the placement and arrangement of components within the MDF structure, and initiate the manufacturing process. This modification aims to enhance student engagement in the project and provide them with a sense of ownership over the robot. The design of conceived example of second robot model is shown in Figure 2.

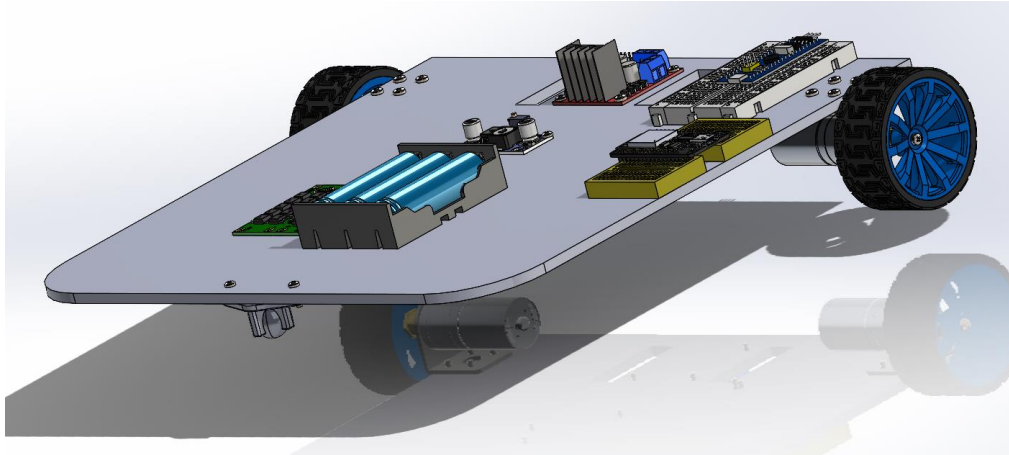


Figure 21. Example of Design of second robot model

A change is occurred in the workshop with additional assistance provided in the odometry and trajectory planning sections. This modification aims to minimize research time and maximize the practical knowledge gained. The subsequent stages of the training process are maintained but with greater detail, including a comprehensive discussion on trajectory planning. Rather than directly addressing the on-board aspect, students will analyze and devise a trajectory planning algorithm based on the robot's mechanical and electrical characteristics. An educational forum has been established for students to share ideas and collaboratively devise a solution. Each student presenting their algorithm is required to explain it to their peers, allowing for analysis and modifications to address any shortcomings. The use of ChatGPT is permitted, provided that the student can articulate the entire proposed code. The subsequent phase involves a discourse on odometry, using the methodology applied in the previous phase.

### ***Results and discussion of the second approach***

The modifications implemented in the second prototype have significantly enhanced the robot's versatility across various aspects. Consolidating all components onto a unified platform has notably streamlined access to diverse electronic components. The use of additional batteries with integrated recharging system has effectively mitigated recharging downtime and expedited cell assembly and disassembly processes. Furthermore, the implementation of dual-chain encoders has notably optimized regulatory tasks by reducing workload demands. Nevertheless, it's noteworthy that the utilization of integrated motors, akin to those found in commercial robot vacuum cleaners, underscores a strategic alignment with industrial standards. The inclusion of two discussion phases in the workshop resulted in enhanced learning outcomes. By allowing the use of the ChatGPT tool, students developed a critical mindset in response to the AI's proposed solutions, effectively leveraging its potential and promoting focused exchanges. This enabled an exchange on an educational platform to discuss proposed solutions based on shared documents as well as a more in-depth analysis of the results.

The student-led debates added an educational dimension to the workshop, fostering idea exchange among participants who recognized themselves as key stakeholders. Among the students, 50% successfully implemented the odometry component, while 90% grasped both trajectory planning and odometry during the evaluation. Unfortunately, none of the groups accomplished the IOT connectivity component. Introducing the IOT aspect in practical work during the same year is recommended to alleviate the complexity of the workshop.

To identify the strengths and areas for improvement in the "Robotics Project" module, a survey is conducted with the aim of assessing the module from the students' perspective. Indeed, students (32 in total) were invited to provide evaluations on various aspects of the module, including overall satisfaction with teachers and support, the engagement and informativeness of practical sessions, the relevance of assessments to the taught concepts, the suitability of teaching resources, preparedness for future projects or professional contexts, the usefulness of teacher interventions, the adequacy of time allocated to practical work, and the module's contribution to enhancing robot design skills. The posed questions are as follows:

- Q1: How would you rate the overall level of satisfaction with the teachers and support provided during the module (1 being very dissatisfied, 5 being very satisfied)?
- Q2: How engaging and informative did you find the practical sessions? (1 being not very engaging, 5 being very engaging)
- Q3: On a scale of 1 to 5, how would you rate the relevance of the assessments and tests to the concepts taught?
- Q4: How suitable do you think the teaching resources provided were for carrying out the project (1 being not very suitable, 5 being very suitable)?
- Q5: How well do you think the module prepared you for future robotics projects or professional contexts (1 being not at all prepared, 5 being very well prepared)?
- Q6: How often did you find the teachers' intervention useful in guiding your work (1 being rarely useful, 5 being very often useful)?
- Q7: To what extent did you find the time allocated to practical work adequate for assimilating the concepts (1 being insufficient, 5 being more than sufficient)?
- Q8: How much do you think the module contributed to improving your robot design skills (1 being very low, 5 being very high)?

The results of the survey conducted with 32 students reveal a high overall satisfaction with the respective module, scoring an average of 4.31 out of 5. Practical sessions received particularly favorable ratings, achieving an average of 4.16, indicating an engaging and informative experience. While assessments and teaching resources were deemed relevant (4.06) and suitable (4.22) respectively, opportunities for improvement were identified, notably in teacher interventions (4.03) and the contribution to enhancing robot design skills (4.19). A detailed analysis of student responses, depicted in Figure 3, highlights a pronounced trend towards high scores (4 and 5).

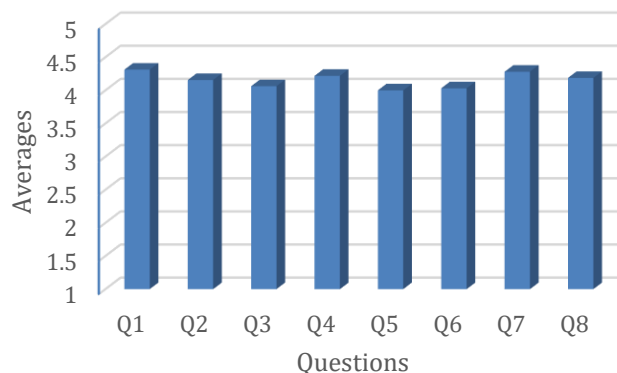


Figure 3. Average of items for each question

Moreover, examining the repartition of student's responses, Figure 4 is established in order to study the overall trend.

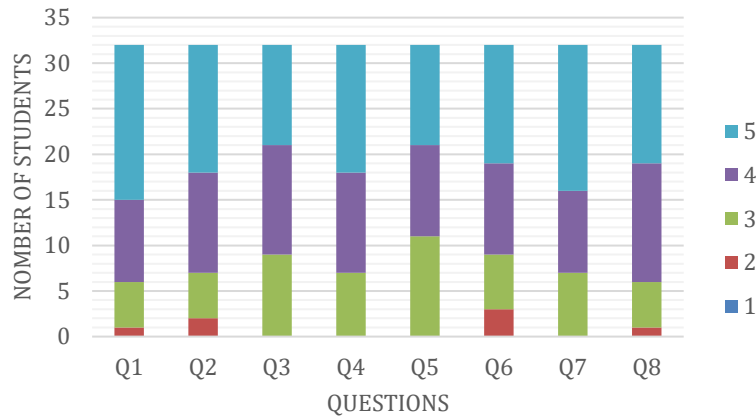


Figure 4. Number of students per item per question

From Figure 4, the results generally reveal a pronounced trend towards high scores (4 and 5) in most questions, indicating an overall satisfaction among students regarding the "Robotics Project" module. This analysis highlights students' preference for positive evaluations, providing a favorable perspective on various aspects of the module. Comparing responses across different questions reveals potential connections, allowing for a deeper understanding of how students evaluate different facets of the module.

In summary, these results, supported by detailed data, offer a solid foundation for targeted adjustments to strengthen positive aspects and address specific concerns of learners, thereby guiding the continuous improvement of the "Robotics Project" module.

## CONCLUSION

In conclusion, the "Robotics Project" module for 5<sup>th</sup> year Electromechanics students serves as an effective bridge between theoretical knowledge and practical applications in mechatronics engineering. While the standardized robot model approach covered essential topics, challenges arose in its finalization. The second approach, incorporating electronic upgrades enhanced learning outcomes despite persistent difficulties with IoT connectivity. Overall, student satisfaction, revealed through a survey, underscores the significance of practical projects in preparing mechatronics engineers for the dynamic and interdisciplinary nature of the professional landscape. Continuous improvements guided by student feedback will ensure the sustained relevance and success of the module.

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# **EMBRACING FAILURE IN ENGINEERING EDUCATION: A COMPARATIVE STUDY OF DESIGN THINKING APPROACHES**

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## **ABSTRACT**

In many engineering sectors, cycles of prototyping have shortened because of new technological advancements and more pressing urgencies to be innovative. As a consequence, important skills and attitudes that were traditionally learned on the job have now become a responsibility of institutes of higher education. Universities are not only expected to develop students to be industry-ready when they graduate, but they must assure they are innovation-ready as well. One way of doing so is to make students innovate on a more regular basis and by making them more comfortable with learning from the failures arising out of such shortened cycles of innovation. Learning from failure is well studied and established in some areas of education, such as the 'Productive Failure' approach in the domain of mathematics. However, lessons learned from such contexts may not immediately apply to the engineering context. By comparing a one semester Design Thinking and Innovation Course with a one-week cross-cultural design thinking workshop at an engineering university in Singapore, this study aims to find out how learning from failure is manifested to engineering students. The study, in drawing on observations, interview data, and students' reflections provides several insights, such as identifying different types of failures that students encounter in their design work and highlighting two core issues (teamwork and grades) that may facilitate or hamper the extent to which students are willing to innovate. This paper gives pedagogical suggestions on how design and innovation can be taught to engineering students, specifically by taking the perspective of learning from failure and its relationship with innovation into account. This paper thus addresses the CDIO Standards 5 and 7.

## **KEYWORDS**

Learning from failure, innovation, creativity, design, Standards 5, 7

## INTRODUCTION

In the dynamic context of contemporary engineering education, institutions are tasked with a critical mission: to cultivate graduates who are not only adept at navigating industry demands but who are also at the forefront of innovation. This mission has gained urgency in light of the rapid prototyping cycles propelled by technological advancements, pressing educators to transcend traditional teaching paradigms. The emphasis has shifted towards fostering skills and attitudes that enable students to manage and learn from failures—a process that has become increasingly crucial given the innovative imperatives of modern engineering practice (Amabile, 1988; Gil, 2018).

One way to stimulate such learning is by putting greater emphasis on the role of failure in education. In rapid prototyping, students are expected to go through many cycles of iteration and in order for these to lead to innovative and new solutions the idea of trial and error is key. But fear of failure may stifle innovation, and the classroom can be a safe space in which students can experiment and develop curiosity to explore different or creative solutions (Foley, Foley, & Kyas, 2022). Fortunately, the education literature has looked into this topic with great interests, noteworthy via the work on 'Productive Failure' as developed by Manu Kapur (2008, 2014). However, the concept of learning from failure, established in domains such as mathematics through the 'Productive Failure' approach (Kapur, 2008), encounters unique complexities within the engineering landscape. Unlike the deterministic nature of mathematical problems, engineering challenges present a spectrum of viable solutions, each accompanied by its own set of uncertainties (Clifford, 1988; Dym et al., 2013).

This divergence calls for an approach to learning from failure that is specifically attuned to the multifaceted nature of engineering design and innovation (Jackson et al., 2021). Prior work illustrated the difference of educational value of failure in different engineering contexts. Cheah (2023), for instance, looked at developing a pedagogy around failure as a learning opportunity in safety critical environments. In chemical engineering education, learning from process plant operation failures can enhance students' understanding of complex systems and fosters resilience. Huang et al. (2023), on the other hand, discussed this in the context of a robotics competition. Their study shows how different types of failures promote creativity and problem-solving in tackling engineering challenges. These examples highlight failure as a pivotal learning tool in developing innovative and resilient engineering professionals.

The study behind the current paper conducts a comparative analysis of two design thinking courses—a semester-long course and a one-week cross-cultural program—at an engineering university in Singapore. This comparison is not merely an academic exercise, but an exploration aimed at unpacking the diverse manifestations of learning from failure in engineering education (Hong & Choi, 2011). The comparative framework allows for an examination of how varying factors such as durations and contexts influence the learning outcomes associated with failure (Kapur & Bielaczyc, 2012).

Engineering students, based on our findings, grapple with a range of failures—incidental, iterative, and intentional. These failures, though integral to the iterative design process, often remain implicit, challenging educators to make the lessons they embody more explicit and actionable for students. This task is critical for the cultivation of innovative thinking and aligns with Amabile et al.'s (2018) perspectives on the social psychology of creativity, emphasizing the importance of context (e.g. the way a classroom is managed or a class is conducted) in nurturing creative problem-solving skills.

Moreover, the study's insights into the dynamics of teamwork underscore the complex interplay between collaboration and innovation for engineering students. Team-based challenges can serve as fertile ground for innovation yet also pose significant obstacles that must be skilfully navigated (Kim, 2005). The role of grades further complicates this landscape, with our findings suggesting that the traditional emphasis on grades may inhibit risk-taking and stifle the innovative spirit required for tackling complex engineering problems (Daly, Mosyjowski & Seifert, 2014; Zhou, 2012).

In the broader context of the CDIO (Conceive-Design-Implement-Operate) initiative, this paper contributes to the discourse on pedagogical strategies that enhance design-implement experiences (Standard 5) and integrated learning experiences (Standard 7). The research provides a nuanced insight in the pedagogical implications of learning from failure, suggesting that embracing such an approach could significantly enrich the educational experiences of engineering students (Stretch & Roehrig, 2021; Marks & Chase, 2019).

Our insights are supported by a substantial body of literature that underlines the transformative potential of embracing failure within educational frameworks. For instance, the work of DiNapoli (2018) and Pan, Kuo, and Strobel (2010) suggest that perseverance in the face of challenging tasks is critical for deep learning, while Tawfik, Rong, and Choi (2015) propose a unified design approach for failure-based learning. These scholarly contributions highlight the need for educational strategies that not only encourage students to confront and learn from failure but also to harness these experiences to fuel creativity and innovation (Amabile et al., 2018; Stretch & Roehrig, 2021).

Furthermore, cultural considerations play a significant role in how students perceive and respond to failure. The work of Cheng and Hong (2017) and Kim (2005) sheds light on cultural dimensions of creativity and learning, indicating that an understanding of these cultural nuances is imperative for designing effective learning interventions in diverse educational settings. These insights are particularly relevant for the cross-cultural component of the study, emphasizing the importance of culturally sensitive pedagogy in engineering education (Hubner et al., 2022). The academic dialogue surrounding failure in education is enriched by the works of Telenko et al. (2015) who explore the boundaries of design thinking in engineering education. Their research underscores the importance of experiential learning and the need for educational models that prepare students for the realities of the engineering profession, where failure is not only a possibility but an opportunity for growth and innovation (Lee, 2020; Foley, & Kyas, 2022).

In conclusion, this paper aims to understand the role of failure in engineering education. It lays the groundwork for the study's methodology and findings, offering pedagogical insights that are aligned with the CDIO Standards and contribute to the advancement of engineering education. Through a compact overview of literature and an analysis of two comparative educational models, this paper aims to redefine the educational approaches to failure, positioning it as a catalyst for creativity, learning, and innovation in engineering.

## **METHODOLOGY**

This study employs a qualitative approach using different methods to explore the manifestation of learning from failure in two distinct design education settings at an engineering university in Singapore. The methodology is designed to capture a holistic understanding of first-year undergraduate students' experiences in two different design thinking courses: a semester-long,

compulsory Design Thinking and Innovation Course (henceforth DTI) followed by approximately 400 students; and a one-week, optional cross-cultural design thinking program (henceforth CC) followed by 19 of our students. The participants consisted of undergraduate engineering students enrolled in the semester-long course DTI, which was structured around a main design challenge on the topic of light and a series of workshops and classes, and/or in the intensive one-week program CC that focused on cross-cultural team-based design projects. The selection of these courses for comparison was intentional, providing a contrast not only in duration but also in the cultural and collaborative dynamics central to the design thinking process.

Data was gathered through a combination of observations, semi-structured interviews, and student reflections (e.g. Ybema et al., 2009; O'Reilly, 2005), with the main aim to capture and understand students' experiences when facing setbacks and what strategies they then employ. Observational data was collected by the research team, which attended course sessions and documented student interactions, their responses to design challenges, and instances of failure and subsequent iteration. Interviews were conducted with a sample of 12 students. We selected students who followed both DTI and CC to allow for more meaningful comparison between the two courses and to represent a range of experiences and perspectives. Each interview lasted for 60-90 minutes. These interviews probed deeper into students' perceptions of failure, their emotional and cognitive responses to challenges, and the learning they derived from these experiences. Student reflections were gathered only from the students participating in the CC course, and these were administered through online reflective journals and feedback forms. In these reflections, students were asked a number of open-ended questions about their experiences and challenges faced, providing a first-person account of their learning journey and the role of failure within it.

The qualitative data from observations and interviews were coded using thematic analysis (cf. Glaser & Strauss, 2006), with an initial coding scheme developed based on the theoretical framework of learning from failure. The coding process was iterative, allowing for new themes related to failure and learning to emerge from the data (Table 1). When analyzing the data we kept our broad exploratory question in mind of how students experience and encounter failure in their work. Hence, our data revealed different dimensions of how students themselves define what it means to fail in their schoolwork, as well as the different types of failure they encounter. In Table 1 we present these themes with more detail, and we elaborate on these in the findings section.

All participants were informed of the study's purpose and provided consent prior to data collection. Ethical guidelines were strictly adhered to, ensuring confidentiality and the right to withdraw from the study at any point. The research design was reviewed and approved by the university's Institutional Review Board.

The methodology of this study is rooted in a comprehensive approach to understanding learning from failure in engineering education. By employing a mixed-methods design, the research captures a rich and detailed portrait of the student experience, offering insights into how pedagogical strategies can be optimized to enhance learning and innovation in design thinking courses. The subsequent findings section will detail the results of this methodological inquiry, presenting the key insights derived from the comparative analysis.

Table 1. Thematic Analysis of the Raw Qualitative Data

| Raw Qualitative Data (Examples)                                                                                                                         | Sub-theme                 | Theme                 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|-----------------------|
| Used the wrong orientation of the cardboard so that the chair is fragile, cannot stand                                                                  | Incidental failure        | Type of failure       |
| Sensors were installed in the wrong location, so that the lights were not on when users waved their hands                                               | Incidental failure        | Type of failure       |
| Wrong match of wires and batteries, small explosion and damage                                                                                          | Incidental failure        | Type of failure       |
| Tried different materials for testing, some materials didn't work or didn't meet the team's expectations                                                | Iterative failure         | Type of failure       |
| Tried different structures for testing, some structures didn't work or didn't meet the team's expectations                                              | Iterative failure         | Type of failure       |
| Instructors let students try to solve problem without lecturing first. While students failed, instructors served as a facilitator to help students out. | Intentional failure       | Type of failure       |
| Time constraint, so that students need to do rapid prototyping                                                                                          | Intentional failure       | Type of failure       |
| Material constraints, so that students need to iterate from low-fidelity materials.                                                                     | Intentional failure       | Type of failure       |
| Create "safe-to-fail" learning environment; Classroom culture of "embracing failures"                                                                   | Intentional failure       | Type of failure       |
| Not innovative; already exist in the market                                                                                                             | Not innovative            | Definition of failure |
| The design doesn't solve problem; Failure would be when our prototype does not function as we wanted it to be                                           | Bad function              | Definition of failure |
| The design does not satisfy me; didn't meet our expectation; The idea does not work as it should be                                                     | Does not meet expectation | Definition of failure |
| Team disagreement; not everyone contribute to the project                                                                                               | Team disagreement         | Definition of failure |
| Something that can be improved; learning process; Earlier fail earlier problem solve                                                                    | Learning process          | Definition of failure |

## FINDINGS

DTI is a one-semester compulsory course for the first-year engineering students in a Singaporean university. The course uses a double-diamond design framework to facilitate divergence and convergence, in which students are asked to identify a problem in a specific geographic area in Singapore and how they can address or solve this problem through the use and design of 'light'. The problem is unknown and the solutions are unknown. CC is a one-week summer cross-cultural design thinking course where Singaporean students travelled to an Indonesian university and teamed up with Indonesian students to design a transformative chair with cardboards. See Table 2 for an overview of the different characteristics of both programs.

Table 2. Information DTI and CC

| Aspect                | Semester-Long Course DTI                        | One-Week Program CC                         |
|-----------------------|-------------------------------------------------|---------------------------------------------|
| Duration              | Full semester                                   | One week                                    |
| Focus                 | Sustained engagement, in-depth exploration      | Intense, rapid problem-solving              |
| Cultural Context      | More homogenous                                 | Cross-cultural teams                        |
| Types of Failure      | Incidental, Iterative, Intentional              | Incidental, Iterative, Intentional          |
| Learning from Failure | More structured, incremental                    | Immediate, adaptive                         |
| Pedagogical Approach  | Iterative learning with multiple feedback loops | Fast-paced, with a focus on quick iteration |

## Types of Failures

### Incidental Failure

In the design process, some failures are unforeseen and incidental. Therefore, students need to think about how to solve these unavoidable and sudden failures. For instance, in the following example, during the design process, students did not notice the characteristics of the cardboard they had to work with. When making transformative chairs out of cardboard in CC, there were some inevitable challenges or difficulties, such as how to make use of the orientation of the cardboard to make the design more robust or to make the chair stronger. Otherwise, it could easily collapse or become fragile. As one student mentioned:

“We didn't even notice the orientation on the cardboard, so the structure we started with was weak and couldn't stand up.”

The second example shows incidental failures encountered by students during the installation of sensors. In DTI, students installed sensors on fixtures of their own design, allowing users to interact with the fixture by waving their hands or making other hand motions. However, if the sensors are installed incorrectly or if other materials interfere with the sensors, the lamp will not light up or the design will fail (see next quote and Figure 1):

“Before the team presentation, we tried out our equipment, and all of a sudden we waved, but the lights wouldn't come on, and we were annoyed at how suddenly they didn't come on. We were annoyed that it suddenly didn't work. However, we took the time to check the problem, because the glass cover on the outside was affecting the sensitivity of the sensor.”

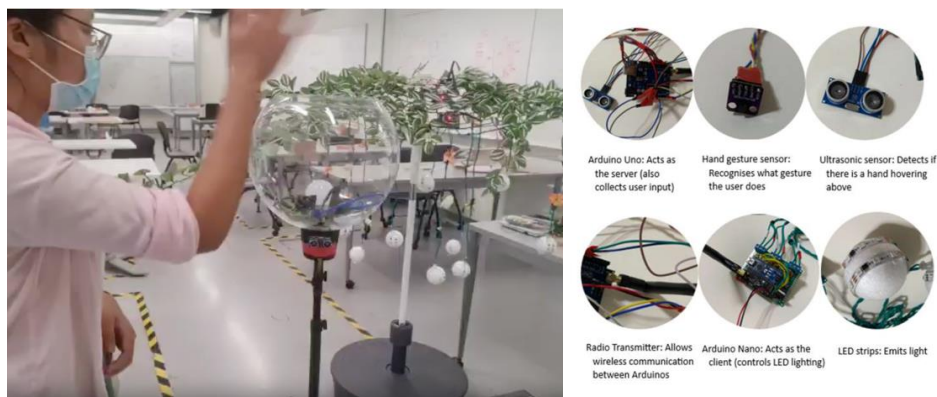


Figure 1: Encountering Incidental Failure in Design

These incidental failures require students to overcome difficulties, find solutions by themselves, and increase their failure tolerance and resilience during the design process.

### *Iterative Failure*

In the Design thinking course, students constantly explore better solutions or designs through iteration. They tried different structures and materials to achieve the desired effect. For instance, Figure 2 shows students' iterations of a structure designed to ensure more social interaction from users' perspectives and for reducing manufacturing cost of the structure.

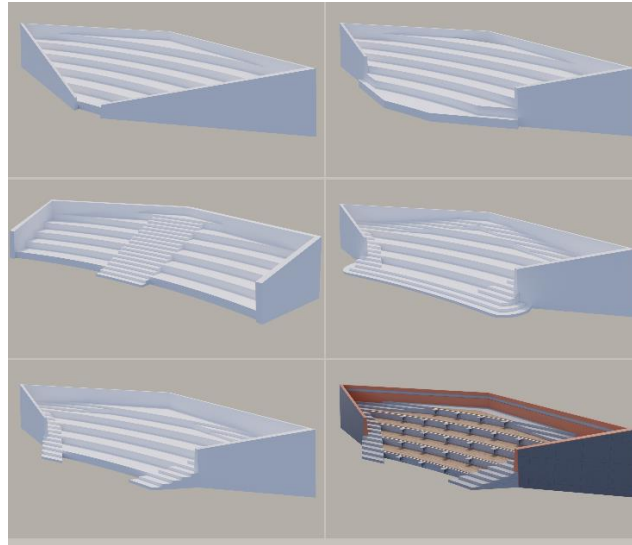


Figure 2. Design Iterations of Structure

Students considered the following while navigating these different iterations:

“User feedback showed that the small entrance made the space feel claustrophobic. The large steps did not align with BCA guidelines for stairways. Later iterations varied the barrier length, angle and height as well as adding approved stairs and handrails in varying locations.”

Figure 3 shows the iterative sketches during students' design of CC. The image on the left one shows the iterative sketches of a chair in the shape of accordion, while the right two images show the iterative sketch of other chairs designed by different teams. Noteworthy, students highlighted the role of sketching here as a catalyst for rapid iteration and in coming to more creative designs:

“We were inspired by the accordion to create a chair that stretches and shrinks like an accordion. We repeatedly iterate, through many unsuccessful attempts.”

“When we sketch, we keep iterating on our concept.”





Figure 3. Iterations of Chairs in CC

### *Intentional Failure*

In both courses, the instructors let the students try on their own, while the instructors act as facilitators to nudge the students to keep trying. When students found that a particular solution did not solve the problem, they looked for the cause and asked the instructors for advice. This intentional failure is a kind of instructors' way of teaching, not unlike 'Productive Failure', in which the students first try on their own, and then through the instructor's explanation acquire a deeper understanding of the knowledge. This thus suggest that instructors can play an active role in helping students encounter and learn from failure in the design process, and that the specific ways in which this is done may contribute to the development of a growth mindset and potentially more creative output. We also found examples of teachers creating a friendly "safe-to-fail" environment to let students try boldly and embrace upcoming failures.

Furthermore, when interviewing students, many of them mentioned time constraint and material constraint while talking about the difficulties and challenges they encountered. In fact, some of these constraints were intentionally built in by instructors. For instance, "time constraint" in DTI, to encourage rapid prototyping; or "material constraint" in CC, so that students need to start with "low fidelity" and iterate more.

### **What DTI Can Learn From CC**

Below (see Table 3), we compare several themes that emerged from our findings as being significant in the design thinking process. They also appeared differently in both courses, allowing us to zoom in on their effects on the potential to learn from failure.

Table 3. Comparison of the Two Courses

|                      | One-semester DTI                                                                        | One-week CC                                                                  |
|----------------------|-----------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Theme                | Glow (Lights instalment and social interaction)                                         | Configurable Chair with Cardboard                                            |
| Team                 | 4-5 Singaporean students                                                                | 2-3 Singaporean students and 2-3 Indonesian students (Business & Management) |
| Graded               | Yes                                                                                     | No                                                                           |
| Reflection           | No                                                                                      | Yes                                                                          |
| Number of Iterations | More                                                                                    | Less (Time constraint, material constraint)                                  |
| Feedback in class    | Two instructors from different backgrounds in each class (engineering and architecture) | Two engineering instructors for the whole program                            |

## *Grading System*

In our interviews with students, students in DTI tended to choose safer design solutions because they wanted to secure their grades. The students followed the rubrics given to them by the teacher and followed the criteria of what is achievable. Particularly in Asia, students are trained for a long period of time to "take tests" before entering university, as well as in the educational culture of their schools and families (Wong, Kwek & Tan, 2020). Often, scores or GPAs are perceived to be more important than the learning process itself. Although the DTI course is not based on traditional exams and is project-based learning, most of the mindset for these first-year students is still based on grades. As long as there are grades, it will have an impact on the students, including the interaction between team members.

"Our team members have some novel ideas, but we feel it's risky, and if we don't achieve them, we'll get a low grade, and we won't have time to start all over again. "

"I still care about my GPA, because it's what I look at when I'm looking for a job, and it's what I look at when I'm applying for my master's. It's a baseline. I know design students look at profiles, but GPA is the baseline."

These quotes show that students care about their grades. They want to secure their grade for their future work-transition or further degree application. If they choose innovative ideas, they are not sure whether they will be able to achieve it at the end of their semester because grades are mainly based on the outcomes. While the process of exploring the novel and creative ideas may be fun to students, this process is not graded or evaluated.

The CC programme, on the other hand, is a cross-cultural summer trip based on an intensive design thinking course, and because it is non-graded, design ideas are varied, e.g., Indonesian cultural elements are incorporated. The team members are more willing to try out 'risky' ideas or new ideas.

"Compared to DTI, we felt a lot more relaxed because, firstly, we were more familiar with the methodology as we had taken a semester of design thinking course compared to Indonesian students, and secondly, we were more willing to take risks and try out new ideas because it didn't matter if we failed, and it didn't have any effect on our GPA."

Through this comparison, we see that the grading system and rubrics of design projects matter. If innovation is indeed a key learning goal of such projects, the process besides just outcome should be measured. Since students attach great importance to grading, it is very difficult to change the students' mindset within a short period of time because it is closely related to the social environment, family education, and the basic education system in a country. Therefore, instructors can consider taking measures to see how students' design and learning process can be evaluated, for instance, via peer feedback, peer evaluation, or rating from external industry people. The revised grading system should be able to encourage students to try out creative ideas, even if they fail, but the process is meaningful and worth trying.

### *Teamwork (Interdisciplinary, cross-cultural, labour distribution)*

We found that teamwork in the DTI course was a huge challenge, and that many problems arose during a semester of collaboration. Due to different perspectives, different habits of working, and different personalities, students found that teamwork presented many problems.

"We had a hard time working together as a team because some students were very reluctant to co-operate and always talked about things on paper and didn't do anything concrete, which caused us a lot of headache."

In the CC programme, half of the students from Singapore, who had already attended the DTI course, and the other half from Indonesia, majoring in Business and Management, worked well together. Basically, the Singaporean students took the lead, played the role of facilitator in the team, and were better at drawing diagrams. The Indonesian students were better at product marketing in Design Thinking and incorporating Indonesian culture into their designs.

"We had a great time working together as a team during the CC programme, probably because we were all from different partner institutions and it was only a week long. But I think it was also because we complemented each other and had a clear division of labour. "

Based on this comparison, a teamwork workshop for DTI students would be an educational intervention to enable students to understand how to work effectively in a team, and divide the workload according to the skills that the team members are good at.

### *Reflection*

During the CC programme (because it is a non-graded program), the researchers were able to pilot with an educational interview - integrated reflective practices - by asking students to fill out Google Forms to record their reflections. Reflection questions included: What are main difficulties/challenges you encountered during this furniture design project? How did you respond to these difficulties/challenges? In future, if you encounter such difficulties/challenges again, what will you do differently? and so on.

While answering the question: "In the future, what will you do if you encounter such difficulties/challenges again?", students mentioned the following:

- Abandon idea and think of a different one.
- Plan ahead and set daily/per-session goals.
- Do some research in advance.
- Try iterations with smaller pieces before committing to the final prototype.
- Prepare a script or learn more deeply about the concept of our design.
- Plan out potential issues before making the prototype.

More importantly, when probed, students had developed new thinking around the role of failure in design thinking. They realized that "failure" is a learning process for them:

- You fail and learn at the early stage, and you can improve and continue faster to success.
- The more you fail, the more you know how to fix, that's where improvement comes.
- Failing often is important is very helpful to create improve iterations and always brings new improvement to the design however, failing early is crucial to actually have time to improvise.
- Failing is part of the process , so we need to find other way to solve a problem that made our design is fail.

This reflective practice encouraged students to reflect on their learning process, the challenges they faced, and how they overcame them. It enabled students to learn from the process and learn from their failures.

### ***What CC Can Learn From DTI***

#### *More Open Themes Encourage Innovation*

The theme of the DTI course is for students to find a problem with the theme of “lights” and explore how they can stimulate social interaction through light installation, while the theme of the CC program is to design a transformative chair using cardboard. DTI has a more open theme, allowing students to find problems and explore unknown solutions to the complex problems in the real world, and to realise social innovation by offering different solutions, not limited to an engineering product design.

Because engineering problems nowadays are becoming more and more complex, choosing a real-world complex topic for engineering students can help students appreciate the journey of problem solving and exploration. Furthermore, problems that are socially relevant or have a direct impact on communities can be particularly engaging. Lastly, solving the real-world complex engineering problems requires interdisciplinary knowledge and skills. It is important to encourage students to draw on knowledge and methods from different disciplines. This can help them think outside the box and find innovative solutions that might not be apparent when viewing the problem from a single perspective.

#### *Increase the Frequency of Iteration*

DTI is a one-semester course based on a two-diamond framework that allows students to complete team-based projects. Through a process of Divergence and Convergence, iteration after iteration is accomplished. The teacher encourages students to explore more and encourage different ideas during the process. One student, in comparing DTI and CC:

“None of our Indonesian students had a background in design thinking, but we had a full semester of the course, especially the training for iteration, so we repeatedly emphasised iteration and the need to keep trying to come up with a better solution.”

“For us Singaporean students, CC programme was like an opportunity for rapid prototyping. Due to the short time frame, we did not have enough time to follow the Double Diamond framework. It is more like a one-week rapid prototyping activity.”

#### *Interdisciplinary Context*

In the DTI, each class is taught by two teachers from different backgrounds, one from engineering and one from architecture. During the design process, the two teachers often have different types of feedback for students, reasoned from their different areas of expertise. This was hard for students but encouraged their thinking across disciplines:

"We were confused at first, because we asked different teachers, and they gave us different advice. Then the teacher told us that we were simulating the real design environment, and that different stakeholders might have different suggestions, so that we could think about how to solve the different feedback by ourselves, so that the design could be more creative and meet the needs of different stakeholders. "

Therefore, during the one-semester design process at DTI, the student received advice from both teachers from different perspectives. Thus, students kept iterating while receiving and incorporating this feedback into their design.

## CONCLUSIONS

The comparative study of DTI and CC at an engineering university in Singapore offers insights into the dynamics of learning from failure in engineering education. Drawing on Amabile's (1988) dynamic model of creativity and innovation, this exploration underscores the necessity for adaptable and context-sensitive pedagogical approaches.

Our study delves into the diverse types of failures encountered by students, aligning with Clifford's (1988) discussion on failure tolerance and extending it to the multifaceted context of engineering design. Specifically, it contributes to recent work on the role of learning from failure as a specific pedagogy that can enhance the learning of engineering students in diverse ways, such as promoting a better understanding of safety (Cheah, 2023) or generating a greater appetite to experiment, take risks and innovate (Foley, Foley & Kyas, 2022; Huang et al., 2023). This further contributes to the broader discourse on culturally aware pedagogies, echoing Kim's (2005) emphasis on the influence of cultural dynamics in learning. Table 4 summarizes these types of failure, each eliciting different responses and adaptations from students, thus contributing to their learning journey in unique ways.

Table 4. Interpretation of Types of Failure Encountered

| Type of Failure | Description                                                 | Learning Experience                                  |
|-----------------|-------------------------------------------------------------|------------------------------------------------------|
| Incidental      | Unforeseen challenges that prompt immediate problem-solving | Develops quick-thinking, adaptability                |
| Iterative       | Emerges from the design process; trial and error            | Enhances resilience, understanding of design process |
| Intentional     | Introduced by educators as learning opportunities           | Encourages risk-taking, exploration of new ideas     |

Our findings challenge the traditional 'Productive Failure' model, proposing a more dynamic framework suitable for the complex, solution-varied world of engineering. This aligns with Tawfik, Rong, and Choi's (2015) call for failure-based learning designs that foster creativity and problem-solving. Our study makes specific contributions to existing literature by demonstrating empirical evidence of diverse learning outcomes from different approaches to failure in engineering education. This research extends the conversation about failure in learning, emphasizing its role as a catalyst for innovation and creativity.

In conclusion, this research underscores the importance of failure as a vital component of the learning process in engineering education. It advocates for a pedagogical shift that values learning from failure, aligning with the evolving needs of the engineering industry. The insights from this comparative study highlight the need for educational strategies that are not only robust and adaptive but also capable of transforming failure into a stepping stone for success. The study's contributions to the field of engineering education are significant, advocating for strategies that foster creativity, resilience, and innovative thinking, thereby preparing students for the unpredictable and multifaceted challenges of the engineering profession.

Specifically, this study has the following implications for engineering educators, primarily centred around CDIO Standards 5 and 7. First, when integrating design thinking into engineering education students need to be nudged in the process to keep trying, keep iterating, as a precondition for being innovative. Second, create a classroom environment that embraces failures, create a safe-to-fail classroom culture, encourage students to learn from failures, try boldly and iterate in the process. Third, adopt a "student-centred" teaching concept in the classroom, allowing students to explore and solve an open-ended real-world complex problem on their own, by facilitating and inspiring students to further explore and iterate when they fail. Fourth, to incorporate grading measures of process into the grading system. For example, through peer feedback/evaluation, and ratings from external industry people. This to enhance the iterative process and encourage creativity. Finally, to develop students' teamwork ability, which is a very important soft skills for future engineers, so that students will realise how to make use of team members' respective strengths and contribute to team projects responsibly. Team diversity here leads to greater divergence of ideas and exploration of innovative ideas.

Encouraging iteration and learning from failure directly supports Standard 5's emphasis on practical learning experiences, as students are more likely to engage deeply with the design-build-test cycle when they are not afraid to fail. Adopting a student-centred approach and focusing on real-world problems aligns with Standard 7's goal of integrated learning, as it facilitates the application of interdisciplinary knowledge.

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# CHATGPT AS A CO-PILOT FOR ASSESSMENT DESIGN REFINEMENT: AN EXPLORATORY STUDY

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## **ABSTRACT**

The evaluation of students' attainment of course learning outcomes is a fundamental aspect of a successful engineering program, exemplified by CDIO Standard 11 'Learning Assessment'. However, earlier research has identified a prevailing gap in assessment competency among faculty. Rooted in established interdisciplinary concepts and theories, this study aims to explore the usage of ChatGPT-4 as a co-pilot to guide faculty in assessment design refinement. To achieve this goal, we adopt a conversational analysis approach, contextualizing our study within the settings of the final exam of the senior course "Wireless Sensor Networks", offered at ESPRIT School of Engineering. We propose a framework to guide the implementation of the conversational analysis method. Our research results illustrate the merits, potentials, and limitations of using ChatGPT as a co-pilot to assist faculty in refining the assessment design process. It also brings into evidence the importance of keeping a 'human in the loop' perspective during the faculty-ChatGPT assessment co-creation activities. Our study can pave the way for further research on other potential applications of "Human-AI co-creation" and augmented man-machine intelligence in a CDIO engineering education.

## **KEYWORDS**

Learning assessment, CDIO, Generative AI, ChatGPT, Engineering education, co-creation, Standards: 10, 11.

## INTRODUCTION

Assessing the extent to which engineering students achieve their program learning outcomes upon graduation is of paramount importance for educational effectiveness, continuous improvement and for meeting accreditation requirements (Ali, 2023). Program Learning Outcomes (PLOs) are generally expressed as broad statements that capture the cumulative disciplinary knowledge, skills, and abilities that engineering students should demonstrate upon completing their educational program. For assessment, PLOs are often mapped to individual courses within the program and the PLOs-Courses mapping matrix showcases how individual courses, collectively, contribute towards achieving the overarching goals set by the program learning outcomes. Unlike the broader PLOs, Course Learning Outcomes (CLOs) are specific to individual classes, focusing on personal and interpersonal skills, knowledge areas, and product, process, system, and service building skills (CDIO, 2020) that students are expected to master within a course, and these contribute towards the fulfillment of the program's broader educational aims.

The design of effective learning assessment instruments to probe students' achievement of course learning outcomes is among the key pillars of effective engineering programs, as reflected for instance by CDIO standard 11 (CDIO, 2020).

Effective course learning assessment goes beyond evaluating students' competencies and grading their academic performance. Its primary added value lies in guiding instructors to continuously refine their teaching material and methods, thus providing a 360-degree loop of critical feedback to continuously improve students' learning and faculty teaching. For example, if an assessment shows that students are struggling with a specific learning outcome, it incites the instructor to revisit the related teaching material and approaches, providing a potentially better learning opportunity for the next cohort.

Despite the importance of designing effective learning assessments in engineering education, earlier research (e.g. Palm, 2019; Villarroel et al., 2018; Fook & Sidhu, 2010) revealed that not all faculty members possess the required competencies in designing authentic learning assessments that are aligned with the stated course objectives and learning outcomes. While the challenges of designing authentic assessments that are valid, reliable, and engaging are well documented (Heritage, 2022), some faculty are still struggling with developing appropriate assessment instructions and establishing clear scoring rubrics. In fact, while some faculty may demonstrate superior performance as subject matter experts, they sometimes lack the necessary knowledge and skills to effectively design authentic assessments. Guskey (2015) argued that faculty professional development programs often privileged teaching methods and technology integration over assessment practices. In its coverage of the actions needed to enhance faculty teaching competence, CDIO standard 10 (CDIO, 2020) emphasizes "assessment of student learning" as an integral teaching competence and highlights the need for faculty development in this area.

For the past years, there has been a growing interest in the application of Generative AI (GAI) and AI-driven conversational models to enhance students' learning and faculty teaching. Previous research has suggested that AI chatbots can effectively assist faculty in creating exam questions and grading students' responses (see, for example, Cheung et al., 2023; Daun & Brings, 2023; Grévisse, 2023; Skrabut, 2023, Chapter 4). However, these studies have mainly focused on showcasing how intelligent natural language processing tools can assist faculty in proposing practice exercises and a variety of assessments, including interactive quizzes, multiple choice exam questions, and fill-in-the-blank test questions. Such an approach tends to favor the passive consumption of information among faculty, without enhancing their creativity and critical thinking skills in designing effective assessment instruments. In addition, earlier studies were mainly focused on leveraging GAI for assessment creation, primarily to liberate faculty time for what is perceived as "more critical" educational endeavors such as preparing course material and providing feedback to students (Skrabut, 2023, Chapter 4).

Drawing on established interdisciplinary concepts and approaches like Human-AI Interaction (HAI) and Augmented Intelligence (Aul), as well as educational theories and approaches including co-creation, constructivism, and connectivism, this study seeks to explore the potential usage of GAI as a mentor to guide faculty in refining the assessment design process. We position the usage of GAI as co-pilot for assessment design as another potential initiative to further bridge the prevailing gap in assessment competency among faculty. To achieve this objective, we adopt a qualitative research methodology that uses a conversational analysis approach, taking ChatGPT-4 as an illustrative example. We contextualized our study within the setting of the senior engineering course "Wireless Sensor Networks" taught at ESPRIT School of Engineering.

In this paper, the term 'co-pilot' is used metaphorically to describe the role of ChatGPT in assisting faculty with refining the assessment design. This usage should not be confused with Microsoft's Co-Pilot, a GAI tool launched in 2023.

The remainder of this paper is organized as follows: Section 2 presents a literature review of related studies. Section 3 details the research methods and procedures. Section 4 presents the results of our study, while section 5 provides a detailed discussion of these findings. Finally, section 6 presents a summary of the key research results, their implications, and some suggestions for future research.

## **LITERATURE REVIEW AND RESEARCH CONTRIBUTIONS**

AI is poised to transform teaching and learning in higher education, with applications ranging from profiling and prediction, intelligent tutoring systems, assessment and evaluation, and adaptive systems and personalization (Bond et al., 2023). Bond et al. (2023) conducted a meta systematic review of the applications of AI in higher education. The study identified several earlier contributions addressing the usage of GAI in assessment and evaluation. These earlier studies were however mainly focused on automating and/or enhancing the evaluative aspects associated with automated grading (Algabri et al., 2021), and personalized feedback to students (Ouyang et al., 2022).

Table 1 summarizes some of the related earlier contributions.

Table 1. Summary of Related Contributions

| Source                 | Research Method   | Key Findings                                                                                                                                                                                                                                                                            |
|------------------------|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fergus et al. (2023)   | Case study        | While ChatGPT can generate good responses for some chemistry questions, it has limitations when it comes to application and interpretation questions, especially those involving non-text information.                                                                                  |
| Gamage et al. (2023)   | Literature survey | While ChatGPT can be useful in providing personalized feedback, support for research and data analysis, and automated administrative services, it poses some challenges associated with academic integrity, reliability issues, and the potential for biases and falsified information. |
| Chaudhry et al. (2023) | Case study        | ChatGPT can provide solutions to the assessment tools used for assessing students' learning outcomes.                                                                                                                                                                                   |
| Kolade et al. (2023)   | Case study        | ChatGPT can generate original academic essays with high-quality but has limitations in providing concise referencing.                                                                                                                                                                   |
| Rybak & Tytenko (2023) | Conceptual study  | A high-level conceptual model was developed to guide ChatGPT generate tests and quizzes. The proposed model has not been tested or validated                                                                                                                                            |
| Daun & Brings (2023)   | Case study        | ChatGPT can be used for the automated assessment of coding exercises, and it can create sample software engineering exam exercises, hence assisting faculty to cope with the tight time constraints in searching for potential assessment questions.                                    |
| Nikolic et al. (2023)  | Case study        | Cross-examining ChatGPT responses to existing assessment prompts from ten subjects showed that ChatGPT did pass some subjects and excelled with some assessment types. Careful finetuning of the input prompts can help in enhancing the reliability of ChatGPT responses.              |

As may be seen, most of the reported studies on using GAI for assessment (see also the work of Meo et al., 2023; Friederichs et al., 2023; Fergus et al., 2023) have focused on evaluating the reliability of AI-driven chatbots in correctly answering quizzes, and exam questions. Fewer studies have focused on using GAI for assessment design and creation. More importantly, studies like those reported in (Skrabut, 2023, chapter 4; Cheung et al., 2023; Grévisse, 2023), mainly viewed ChatGPT as a time-saver for faculty, having the potential to quickly generate a test bank of questions (predominantly multiple choices) and answers in few seconds. Not only does such an approach undermines the role of assessment in higher education, but it also hinders critical thinking among faculty by stimulating passive consumption of information.

This research makes the following two main contributions:

- Based on established interdisciplinary concepts, theories, and approaches that are detailed later in this section, our study explores the usage of GAI as a value-added tool and a mentor to guide faculty in refining the assessment design process. In doing so, it emphasizes the importance of human-AI co-creation in bridging the gap in assessment competency. Instead of promoting the passive consumption of information, the proposed approach aims to stimulate some higher-order thinking skills among faculty when they actively engage in meaningful discussions and collaborative conversations with AI-driven chatbots.
- We support this exploratory study with a qualitative research methodology, which employs a systematic and iterative conversational analysis approach to mimic the interaction with a professional educational expert.

Our research is rooted in and guided by the following established concepts, theories, and frameworks:

- Augmented Intelligence (Aul) and co-creation (Dellermann et al., 2021; Xue et al., 2022): Aul is a subset of AI that emphasizes a collaborative model where humans and AI work together to enhance cognitive performance, problem solving and decision making through a co-creation process. In doing so, people and AI work iteratively to refine tasks, goals, and solutions. Aul can also enable humans to acquire new ideas and perspectives that they might not have considered on their own. It also promotes the "human in the loop" design principle to emphasize human oversight, ensuring that AI enhances rather than substitutes human capabilities.
- Human-AI Interaction (HAI) framework (Abedin et al., 2022; Rezwana & Maher, 2023; Sreedharan, 2023): HAI refers to the dynamic interaction between humans and AI systems. HAI is crucial to AI as it shapes how humans engage with AI in an effective and efficient manner. In the context of our study, HAI provides some useful guidelines that we followed to optimize our interactions with ChatGPT during the assessment co-design experiments. These include keeping clear, specific, and engaging prompts, avoiding information overloading, providing feedback, and seeking explanations for the generated responses, cross-examining and critiquing the validity and accuracy of the generated responses, finetuning and revectoring the conversations when needed to make them useful, usable, and productive. To this regard, Ng et al. (2023) highlighted the growing need for faculty to equip themselves with adequate digital competencies to make best usage of AI in their teaching, learning and assessment. Understanding the distinction among GAI (AI algorithms capable of generating new content), Aul, and HAI, as defined above, is useful to apprehend the layered approach of our study. We employ GAI as the specific type of AI technology, we adopt HAI to set the stage for effective human-centered AI use and we draw from Aul to advocate for a "human-in-the-loop" design approach.
- Constructivism (Jonassen, 1999): Our research has been inspired by the principles of constructivism whereby faculty actively construct knowledge through meaningful interaction with ChatGPT to co-design assessments. In doing so, it relies on the important concepts of active engagement, iterative interactions, and dynamic feedback. Some earlier studies have underscored ChatGPT's role in fostering constructivism learning by enabling learners to actively negotiate meaning, co-construct knowledge, engage in self-reflective metacognition activities, and participate in dynamic scaffolded learning activities (Rasul et al., 2023; Hatmanto & Sari, 2023; Tabib & Alrabeei, 2024).
- Connectivism (Siemens, 2004): The collaborative nature of the faculty-ChatGPT interaction in the co-design of assessments is in alignment with the connectivism principle that knowledge networks and collective intelligence facilitated by ChatGPT play an important role in stimulating a dynamic learning process.

## METHODS AND PROCEDURES

### *Methods*

As an exploratory study for the potential usage of AI-driven conversational models as co-pilots for assessment design refinement, we opted for a qualitative research methodology that uses a Conversational Analysis (CA) approach. Conversational Analysis (CA) is an approach developed within the field of sociology that analyzes the mechanisms and patterns of human interactions in natural conversations. It emphasizes the role of talk-in-interaction and how conversational turns are constructed among participants to achieve mutual understanding (Sidnell & Stivers, 2013).

We adapted the CA approach from its traditional social science conversational context, towards a human-AI perspective, with ChatGPT mimicking the interaction with a professional educational expert. The CA approach fits well with the aims of this study for the following two main reasons:

- It incarnates the iterative nature of the conversation that takes place between the researcher and ChatGPT, reflecting the adaptation and learning that take place during the conversation. In fact, the CA approach captures the evolvement of ChatGPT's responses to the researcher's prompts over time, based on the follow-up prompts, requests for refinement and clarifications, and ChatGPT's learning from previous interactions.
- It can showcase how ChatGPT handles misunderstandings, disagreements, or incorrect information, and how it corrects itself.

We contextualized our study within the setting of the first-year graduate engineering course "Wireless Sensor Networks", taught at ESPRIT School of Engineering. This course aims to introduce students to the main concepts and challenges associated with the design and deployment of Wireless Sensor Networks (WSNs) and the applications of these networks in the context of smart-cities and Internet of Things (IoT).

The course is assessed using the following instruments:

- Classwork: Presentation & WSN simulation labs (30%)
- Team project (20%): Analysis, design and implementation of a WSN solution
- Final exam (50%)

The course has the following CLOs:

*CLO.1.* Explain the basic concepts and applications of wireless sensor networks.

*CLO.2.* Describe wireless sensor network types, components, operations, challenges, and sensor node architectures.

*CLO.3.* Demonstrate understanding and usage of WSN standards and protocols (physical, data link, network, and application layers).

*CLO.4.* Appraise the usage of WSN simulations.

*CLO.5.* Investigate potential deployment of WSN in the context of smart cities/ IoT.

*CLO.6.* Conceive, design and implement a complete WSN solution.

To keep the scope of this study to a manageable level, we focused on the final exam as an illustrative assessment instrument, hence excluding the classwork and team project.

The final exam has been designed primarily to evaluate students' understanding of key WSN concepts and principles (CLOs 2 & 3). It also included an element that assesses students' ability to conceptualize and design a small-scale WSN solution (CLO6). The original exam developed by the faculty consisted of 7 essay-type questions and one case-study. It is a closed-book exam, set for a duration of 1.5 hours.

### **Procedures**

The general framework that guided our conversational analysis approach is depicted in Figure 1. The framework has been developed based on thorough desktop research on best practices in interacting with AI-driven conversational models and it has been guided by the concepts, theories and frameworks described in the previous section. We adopted a systematic and iterative conversational approach to mimic the interaction with a professional educational expert. In addition, recognizing that well-defined ChatGPT prompts are the recipe for a successful conversation, we took special care to ensure that each prompt is clear, concise, specific, and focused. Further, to avoid overwhelming ChatGPT with lengthy details, we decided to address each exam question individually.

As may be seen in Figure 1, we started by providing ChatGPT with the general context of the intervention, including general information about the course, its level, description, content, and CLOs among others. We also stated our goals, objectives, and expectations, with a special emphasis on conveying our aim to collaborate to co-design and iteratively refine each exam question. We prompted ChatGPT to act as a senior engineering professor and a leading pedagogical expert. We entered each final exam question, one at a time, along with its associated CLO and Bloom's cognitive level. We leveraged ChatGPT's analytical capabilities to prompt it for critiques, insights, and feedback. We regularly sought clarifications by posing follow-up questions and specifying constraints. We cross-examined the validity and the appropriateness of the generated ChatGPT responses, and iteratively refined the original questions until we achieved satisfaction with the final outcomes. Occasionally, we had to replace an exam question with a better alternative suggested by ChatGPT. We also performed a final iteration to eliminate potential overlaps among the revised questions. At the end, we prompted ChatGPT to generate the answer for each validated question, along with its grading rubric. These were also iteratively refined until validated.

Throughout our interactions, we maintained a journal to capture details of the iterative aspects of our intervention: Queries, ChatGPT's responses, critique of the responses, follow-up prompts, subsequent refinements and modifications, and the rationale behind them, among others. An extract of the journal can be found in ([Prompt\\_Journal, 2023](#)) on GitHub.

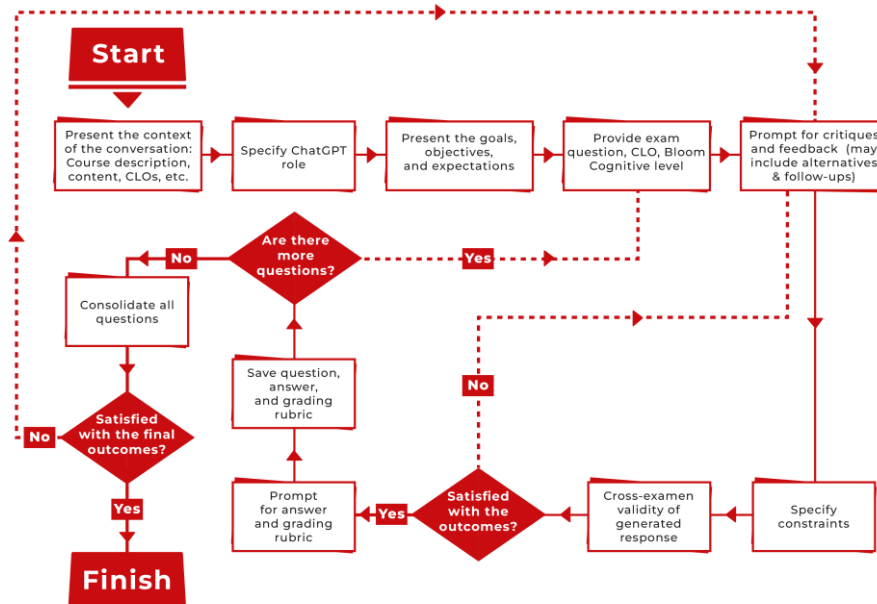


Figure 1. Framework of the Researchers' Conversation with ChatGPT

## RESULTS

Because of lack of space, we will only report herein sample of the faculty-ChatGPT interactions. The reader is referred to (Prompt\_Journal, 2023) for full details regarding the conversations that took place to refine the other 7 exam questions.

 You:

Your role: Act as {senior Engineering Professor and a leading pedagogical expert} . As a {co-pilot}, I would like you to collaborate with me (the instructor) to {co-design} and {refine} each proposed exam question, one at a time. Just say OK.

 ChatGPT:

OK.

 You:

Your task: I would like you to {critique, refine, and provide constructive feedback} on each submitted final exam question, taking into account the corresponding CLO, Bloom's cognitive level, and the appropriateness of the question in terms of clarity, specificity, and alignment with best assessment practices. Are you ready to start with the first question?

 ChatGPT:

Yes, I'm ready to start with the first question. Please go ahead and share it.

 You:

The first question Q1: {What kinds of design and resource constraints does a wireless sensor node have?}. This question is meant to assess CLO.2. It is associated with Bloom's cognitive level of {understanding}.

 ChatGPT:



### Q1 Critique and Refinement:

Original Question: "What kinds of design and resource constraints does a wireless sensor node have?"

Critique:

Clarity and Specificity: The question is somewhat open-ended, which might lead to varied and possibly incomplete responses. It doesn't specify the context or type of wireless sensor network, which can have different constraints based on their applications.

Alignment with CLO.2: This question aligns well with CLO.2 as it explores the understanding of components and operations of WSNs, but it could be more targeted to extract specific knowledge relevant to sensor node architectures.

Bloom's Cognitive Level: It currently addresses the 'Understanding' level appropriately but could be enhanced to touch upon 'Application' by asking for real-world examples or implications.

Refinement: To make this question more effective, consider adding a specific context or application. For instance:

Revised Question: "Considering a wireless sensor network deployed in a smart city environment, identify and describe the design and resource constraints typically faced by a sensor node in this context. How do these constraints impact the architecture and functioning of the sensor node?"

This revision:

Provides a clear context (smart city), prompting students to think about specific applications.

Encourages students not only to list constraints but also to discuss their impact, deepening their understanding and application of the concepts.

Are you ready for the next question or is there anything else to refine in this one?



You:

Thank you. Can you suggest a modification to question Q1 to target the same objective but reframe it indirectly in the context of an application, targeting a higher-order cognitive level?



ChatGPT:

Certainly! To reframe question Q1 in the context of an application and target a higher-order cognitive level, we can shift the focus to evaluating or creating scenarios based on the given constraints. This approach will elevate the cognitive demand from merely understanding to analyzing, evaluating, or even creating, which are higher levels in Bloom's Taxonomy.

Modified Question:

"Imagine you are tasked with designing a wireless sensor network for monitoring environmental conditions in an agricultural setting. Describe the specific design and resource constraints you would need to consider for the sensor nodes in this application. Additionally, propose a solution on how you would address one of these constraints in your design. Justify your choices based on the operational requirements and limitations of the sensor nodes."

This modification:

Places students in a real-world scenario, requiring them to apply their knowledge in a practical context (higher-order thinking).

Asks for a description of constraints (Analysis), a proposal for a solution to one of these constraints (Synthesis/Creativity), and justification of their choices (Evaluation).

Ensures that students not only understand the concepts but also can apply and evaluate them in a specific application, aligning with CLO.2 and targeting a higher cognitive level.

Would you like to proceed with refining another question, or is there anything else to adjust in this one?

## DISCUSSIONS

After engaging in dialogue with ChatGPT to assess and refine the proposed exam questions, we came to the following main observations:

- ChatGPT was extremely useful in critiquing our proposed questions and in suggesting viable alternatives. ChatGPT proved highly valuable in transforming straightforward questions, initially set at the comprehension cognitive level, into more challenging ones aimed at higher cognitive levels, such as application-type tasks.
- ChatGPT did mimic a skilled academic mentor by providing sound, clear and specific justifications when providing feedback and suggesting new alternatives.
- ChatGPT's answers to some of our proposed exam questions were very enlightening and these enabled us to enrich the course's content.
- When prompted to integrate aspects related to the United Nations Sustainable Development Goals (UN SDGs) into the case study question, ChatGPT provided an interesting and well justified proposal. The same applied when we prompted ChatGPT to propose exam questions that are aligned with one of the CDIO standards (e.g. last page in [Prompt\\_Journal, 2023](#)). It should be noted that while UN SDGs are not explicitly reflected in the current WSN course learning outcomes, our intention to embed SDG concepts into the case study question stems from the broader program educational aim to promote interdisciplinary learning and to highlight the relevance of technological innovations like WSNs in addressing pressing sustainability challenges. This also aligns with CDIO Optional Standard 1 on Sustainable development (CDIO, 2022).
- ChatGPT performed very poorly when analyzing a picture associated with an exam question. Refer to the sample case on page 8 in ([Prompt\\_Journal, 2023](#)). A similar very mediocre performance was also noticed when suggesting a graphical solution (ibid, page 18). In particular, the image generated by ChatGPT as an answer to one of our proposed exam questions was quite unusual and unexpected.

As faculty, we found the conversations with ChatGPT very meaningful, interesting, and informing. These conversations also stimulated our curiosity, as well as our analytical, critical, and creative thinking. We also recognized the necessity of maintaining a 'human in the loop' perspective during our interactions with ChatGPT, given the occasional inaccuracies in the automated responses. This human insight perspective is crucial for several reasons: First, it acknowledges the fact that ChatGPT can make mistakes or generate inappropriate responses. Second, it recognizes that when ChatGPT deviates from the context of the assigned task, human intervention is needed to guide it back on track, ensuring relevance of the response. Third, our feedback can help ChatGPT to continuously improve its training model and hence enhance its reliability.

Our research findings provide evidence on the merits of the collaboration between humans and AI in co-creation and new idea generations, as suggested by the Aul and co-creation frameworks (Dellermann et al., 2021; Xue et al., 2022). Our research also illustrates how knowledge can be constructed during the exam co-design collaboration with ChatGPT through active engagement, iterative interactions, and feedback. This process aligns with the principles of constructivism (Jonassen, 1999).

As mentioned by Kamoun et al. (2023), these meaningful engagements between the human and the AI-driven conversational model are most likely to become life-long learning competencies for faculty.

## CONCLUSION AND SUGGESTIONS FOR FUTURE RESEARCH

This study was motivated by earlier research findings that highlighted the prevailing gap in assessment competency among faculty and the need for creative and effective solutions to address this shortcoming. It adopted a conversational analysis approach, within the context of a senior engineering course's final exam, to showcase the potentials and limitations of using ChatGPT-4 as a co-pilot in assisting faculty to refine the assessment design process.

Unlike most related previous studies that promoted the passive consumption of information among faculty by simply soliciting ChatGPT to propose assessment questions, our approach promotes collaboration and co-creation. It uses ChatGPT as a co-pilot for assessment design refinement, while keeping a 'human in the loop' perspective.

Our research contributes to advancing the body of knowledge in engineering education by providing evidence that, when properly orchestrated, active engagement and meaningful interactive conversations with GAI systems can actively promote higher order thinking skills among faculty, enabling them to collaborate with GAI chatbots to co-create assessment tasks that reflect better creativity and enhanced effectiveness. This can pave the way for further research on other potential applications of "Human-AI co-creation" and augmented man-machine intelligence in a CDIO engineering education.

This study has several limitations: First it is of limited scope, being focused on a single course, which also makes the results not necessarily generalizable to other educational contexts. Second, being focused exclusively on the final exam, our study does not consider other forms of assessment instruments such as projects. Third, our study does not incorporate student feedback or perspectives on the outcomes of the co-created assessment.

Research is underway to address some of the limitations mentioned above.

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# **A UNIFIED DIDACTIC FOUNDATION FOR AARHUS UNIVERSITY'S TECH FACULTY: EXPERIENCES AND IMPACT**

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## **ABSTRACT**

This paper describes the data collection and analysis of a survey on the awareness and usefulness of a didactic foundation among the educational management at Aarhus University's TECH faculty. The didactic foundation is a document containing a set of principles and guidelines for designing and delivering high-quality education. The survey was conducted using a web-based questionnaire that was sent to 31 respondents who had different roles in the educational management, such as head of degree program, deputy head of department, vice dean, etc. The response rate was 68%. The research found that most respondents are aware of the didactic foundation document and see it as a useful tool for enhancing teaching quality and communication. Despite its usefulness, implementation is hindered by lack of resources, unclear mandates, and lack of motivation among faculty. The content is generally agreed upon, but respondents highlight challenges in practical implementation. The responses may reflect the dual roles of respondents as both teachers and part of the educational management. The paper describes several follow-up strategies. It emphasizes the importance of making educational resources easily accessible and fostering communication among educational management, teachers, and students. It suggests conducting a follow-up study to understand the level of awareness about the didactic foundation among students and teachers. We also highlight the need for integrating the foundation into existing events like pedagogical days and section meetings, to avoid 'meeting fatigue' and foster discourse on educational quality. Finally, the paper underscores the didactic foundation's role in facilitating a smooth transition for new students and promoting student retention.

## **KEYWORDS**

Pedagogical development, didactic foundation, education quality, teaching and learning, change management, Standards: 6, 10, 12.

## INTRODUCTION

In the realm of higher education, it is a common phenomenon for institutions to assert their commitment to 'high quality learning and teaching' (Harvey & Green, 1993). These assertions are often found in mission statements, where universities and colleges pledge to deliver excellent teaching and foster a high-quality learning environment (Middaugh, 2010). However, the clarity and strategic pursuit of these objectives are often questionable (Gibbs, 2010). In many instances, the definitions of 'excellent teaching' and 'high-quality learning environment' remain ambiguous (Prosser & Trigwell, 1999). The strategies employed by these institutions to achieve these objectives are diverse and often reflect the historical traditions, values, and practices inherent to each institution (Tight, 2012). Therefore, it is imperative for higher education institutions to clearly define and strategically pursue their teaching and learning objectives to ensure the delivery of high-quality education.

In January 2022, the Faculty of Technical Sciences (TECH) at Aarhus University (AU) established a working group tasked with formulating a didactic framework for instructional practices within the TECH domain (TECH faculty at Aarhus University, 2023). This initiative arose in response to the imperative of constructing a unified educational platform, fostering pedagogical competence enhancement and other scholastic endeavours within the faculty. This was precipitated by a recent history of organizational consolidations and transformative alterations, culminating in the formulation of a new collective strategic framework. The primary mandate of the working group was to delineate pivotal elements in support of forthcoming pedagogical approaches at TECH, and to proffer a universally recommended foundation upon which TECH instructors could collectively scaffold, deliberate, and enhance their instructional methods. This work was reported and evaluated in Øien & Bennedsen (2023), with a focus on the content, the development process, and the relation to the CDIO framework. The foundation is both inspired by and aligns well with the CDIO standards and syllabus but was deliberately simplified and 'translated' to local conditions and culture to support broad understanding and ownership.

Now the didactical foundation has been around for almost a year, so one may expect to see some concrete results from use of the work. Hence, this paper will evaluate the TECH faculty's experience with the didactic foundation so far, and most importantly, its impact – e.g., on educational development, strategic priorities, pedagogical choices, and communication strategies. Such impact may be gauged at several different levels:

- The **educational management**: The vice dean of education, deputy heads of department for education, study program responsible
- The **general management**: Heads of departments, heads of sections
- The **teachers and course responsible**. Each course can have several teachers, one is the responsible one for e.g. changes.
- The **students** at TECH

In this paper we will concentrate on assessing the knowledge of the didactic foundation in the *educational and general management*. Leaders in academia are important for the change to happen; not because they manage change but, as Buller (2014) note "*It's something that they lead, initiate, guide, and occasionally capture*". Therefore, we aim to assess whether the key actors on these levels know that the didactic foundation exists, do they understand and agree with its recommendations and guidelines, which of them have actively used it or been explicitly exposed to it, how have they used it, what is their general perception of its usefulness, do they see challenges or barriers for its use which need to be addressed, etc. The assessment is



done via a survey. This paper will analyse and reflect upon the survey responses, with the aim of identifying transferrable follow-up strategies that may serve to strengthen the positive impact of such a framework.

## RELATED WORK

Gedda, Nilsson, Stenberg and Post (2016) elucidate the development of "The Pedagogical Idea" at Luleå University of Technology. This initiative aimed to communicate the core values of teaching and learning across the entire university, encompassing diverse fields such as healthcare, art, and teacher education. However, the authors highlight that this initiative was born out of a less successful development process that led to the creation of "The Creative University". This concept incorporated elements of Knowledge Building and Arenas for sharing of practice but was met with resistance due to its top-down implementation approach. The authors argue that the transition of these concepts to the teachers, who were expected to implement them in their teaching contexts, was not adequately facilitated.

Furthermore, "The Creative University" was grounded in the principles of student-centred learning, which necessitated a high level of educational knowledge and teaching skills among the university professionals. This, according to Gedda et al. (2016), posed significant demands on the faculty.

Many universities have introduced pedagogical training courses and the solution to achieve better teaching (Ödalen, Brommesson, Erlingsson, Schaffer, & Fogelgren, 2019). However, they find

*the positive effects of pedagogical training courses to be present mainly in the group of participants with less than three years of teaching experience (p. 339)*

Additional tools for enhancing the teaching are thus needed. Warfvinge, Roxå and Löfgren (2018) finds that a critically important element for enhancing teaching quality is to develop arenas where the teachers discuss their teaching, stating that '*academic leaders must ensure that teachers have the opportunity to engage in informed pedagogical discussions in their workplace*'. But there is a need for structuring the discussion; this is the aim of the pedagogical framework.

## RESEARCH DESIGN

This section describes how we have collected and analysed data.

### ***Respondents***

The focus of this paper is educational and general management. The educational management structure for the TECH faculty has the following roles:

1. **Head of degree program (HoDP):** In total there are 26 bachelor's and master's degree programs at TECH. Several of the degree programs have the same HoDP, in total the number of HoDPs are 21.
2. **Deputy Heads of Department for education:** Five departments at TECH have educations, each have a deputy head. Two are also HoDP.
3. **Vice Dean for education**
4. **Head of Study administration**

5. **Head of section, Board of Studies Support and Studies Quality Assurance,**
6. **Member of study board:** TECH have two study boards (one for the engineering programs, one for the agricultural science educations). Five faculty are members, two have one or two of the other roles.
7. **Director of Studies:** Associated with the study programs is a director of studies. One of the directors of studies is also HoDP.

In total there were 31 respondents. Some had more than one role; consequently, we asked people to state their role when answering.

### **Data collection**

Respondents are very busy people. We expected the best way to get information within the available time constraints, was to allow the respondents to answer at a time of their own choosing, and consequently created a web-based questionnaire focusing on the awareness, usefulness, concrete use, agreement, enablers, and barriers among the respondents. The questionnaire contained both closed-ended and open-ended questions. The questionnaire was initially developed by one of the authors; the second author subsequently quality-checked the questionnaire. Appendix A contains the complete questionnaire. Later, we expect to get more detailed information based on the responses by interviews.

An email invitation was sent out to the 31 respondents; after 1½ week a reminder was sent out.

## **ANALYSIS AND FINDINGS**

This section describes the key findings based on analysing the responses from the respondents.

### **Response Rate**

The questionnaire was distributed to 31 respondents based on their role in the educational management at TECH. 23 answered the questionnaire (20 completed it, 3 gave some answers), giving a response rate of 68%. Several have different roles, therefore the first question focused on what role the respondents took upon them when answering the questionnaire (21 out of 23 answered):

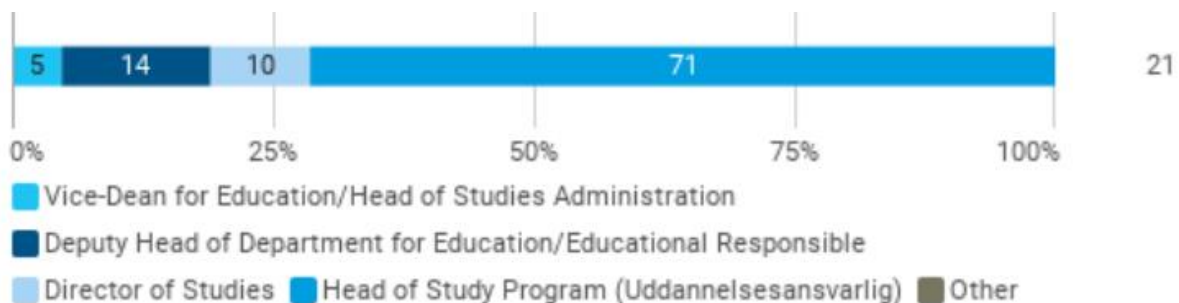


Figure 22: Role of the respondents.

### **Awareness and usefulness**

The respondents were subsequently asked about their awareness of the didactic foundation (Figure 23). The didactic foundation was established about a year before the survey was done and had been shown and discussed in some settings.

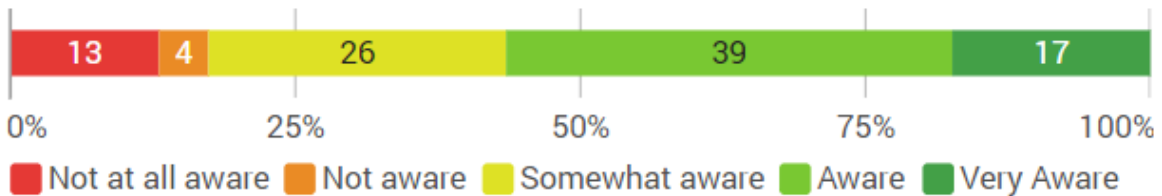


Figure 23: Awareness of the didactic foundation (23 answers)

The respondents who were not aware of the didactic foundations all had the role of Head of Study Program (3 respondents out of 17).

Half of the respondents found it useful or very useful (Figure 24).

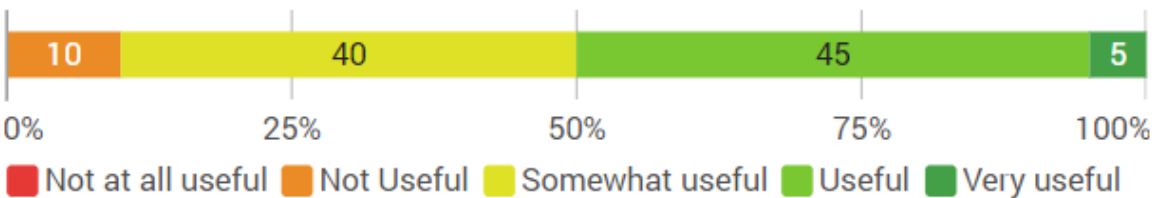


Figure 24: Usefulness of the didactic foundation

Again, the respondents who found the didactic foundation “not useful” were Heads of Study Program (2 out of 15 answers). An interesting detail is that one of the “not aware” respondents found the didactic foundation “useful”.

When asked about the rationale for their evaluation of the usefulness, the most common answer was that it is useful but that more help with implementation is needed.

### **Understandability and agreeability**

When asked if there are elements of the didactic foundation that they do NOT understand, only a few answered, and the answers were mostly about concrete things that are not currently in place (e.g. optimal planning, the time plans arriving very late). Only one respondent had a concrete issue with the description:

*Not happy with the term institution - I need person somebody to be held accountable. Not just [building service] or IT or whomever contractor has been assigned to provide facility service. Make it accountable. Responsible for "Students" are clear, for "Lecturer" are clear. Institute not.*

The didactic foundation is in general seen as a description that the respondents do not disagree with. It is seen as something that describes aspects of good teaching and learning.

## Plan for use

The respondents were asked “*how do you plan to use the didactic foundation*” (Where do you plan to use the didactic framework. There were given a number of possibilities; these possibilities were generated from literature and on the basis of common problems and practices experienced by the authors:



Figure 25: Where do you plan to use the didactic framework.

The “upper management” (Vice dean for education/Head of Studies administration, Deputy head of department and director of studies) all focus on assessment/enhancement of quality (teaching, infrastructure, setting goals, accreditation).

In the introduction and communication about the didactic framework, it has been stressed that it is not intended as a measuring stick, but a dialogue tool. Therefore, it is somewhat surprising that 15% wants to set goals and measure the quality of teaching.

## Barriers

The respondents were asked to indicate what (if any) barriers they could see to the use of the didactic framework (Figure 26: Barriers.):

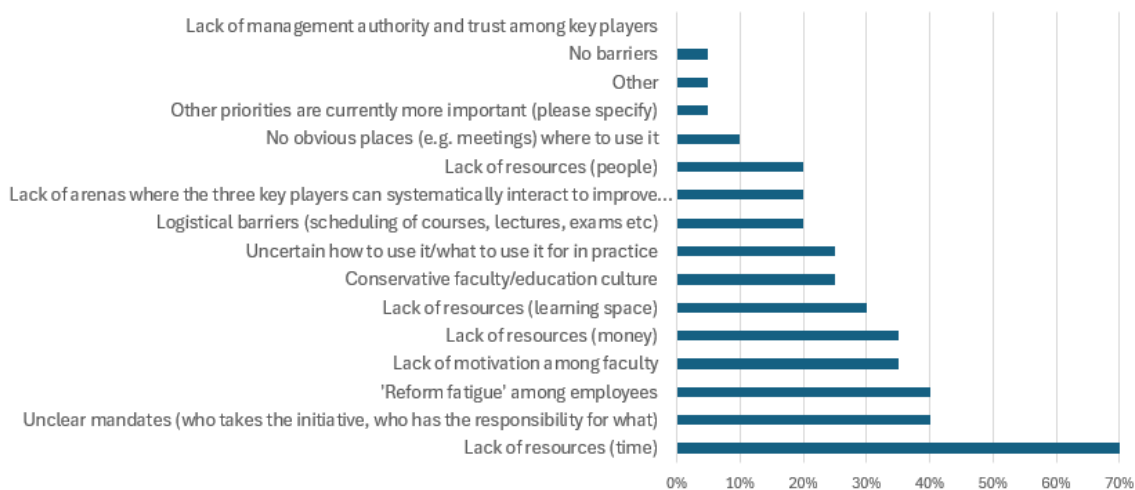


Figure 26: Barriers.

As in other surveys, time is a very critical factor. The workload of academics has increased, leaving less time to develop one's pedagogic competences (Tight, 2010). Higher education has undergone such remarkable transformations over the last decades implying that the teachers may feel a "reform fatigue" (Krücken, 2014)

## **DISCUSSION OF THE KEY FINDINGS**

Most respondents are aware of the didactic foundation document, and report that they understand its contents and see it as a (potentially) useful tool. Some comment that it is "hard to disagree with". We see this as a positive thing, as the intention was not to make something controversial, but to create a tool to strengthen a dialogue among already very qualified teachers. Another part of the motivation for the foundation was to create a shared basis which could serve to integrate several academic subcultures at the merged TECH faculty; also, in the light of this goal it is a good thing that so many see the points in the document as 'obvious', 'hard to disagree with', and 'just stating what we already know'. This makes the more developed description an easier starting point for a dialogue.

The most common reported areas of (planned) use among the respondents are: communication to staff and students (55 %), enhancement of the quality of teaching (45 %), enhancement of quality of infrastructure/facilities (20 %), and creation of new fora/arenas for discussing education quality (20 %). The foundation is also seen as useful in planning of e.g., study programs/courses/infrastructure. It is seen as particularly useful as a dialogue and communication tool. More than half of the respondents (> 70 % of those who answered) have already used parts of the document, with particular focus on the roles of lecturer and student. This indicates that the implementation is on its way. Naturally, one could hope for a 100% usage, but only one year has passed since the launch.

The most common barriers seen for use among respondents are lack of resources (time, money, learning spaces, people – in that order, with time the by far most important), unclear mandates (responsibilities), and lack of motivation among faculty. Many of the study programs taught are professional bachelor programs, where the staff's focus point is mainly teaching. In the later years, it has been very difficult to attract professionals to become teachers (the typical teacher for a professional bachelor's program holds a master's degree and have 10+ years of industrial experience).

Several respondents point out in their written comments that the document is 'hard to disagree with', is uncontroversial, and points to a lot of good intentions - but that they see several challenges related to implementing the guidelines in daily practice, due to lack of e.g., time, suitable learning spaces, administrative facilitation, or (institutional) management support. The degree program responsible (the major number of respondents) also teach themselves, thus one could speculate if some of the answers given are more from their role as teachers rather than their role as part of the educational management.

## **FOLLOW-UP STRATEGIES**

On the practical side, the first (and easiest) thing to do is to make the description easier to find and access on the departmental website.

Knowledge about the didactic foundation is high among the educational management, but is it also high among teachers or students? A follow-up study on this would be a very relevant starting point since the implementation challenges and strategies for successful follow-up might be very different depending on the knowledge level of the involved parties.

The responses also illustrate the adage that it is all about 'Communication, communication, and communication'. Even among the educational management, three out of the 23 who answered the questionnaire were still unaware of the existence of it. One can only speculate about the degree of knowledge among the teachers, but it seems clear that talking about it, or sending info in a newsletter, is not enough. One strategy might be to use it at departments' pedagogical days/seminars/... - as a way for teachers to exchange ideas on how they facilitate good teaching – e.g., how do you show your passion for the student's learning, how do you ensure that you have necessary knowledge about the other courses the students are taking, etc.

Introduction to new students: When students start at the university, it is a big culture change for them. Tinto (2012) writes in his classic work on student transfer from high school to university that a strong commitment to quality teaching, and the building of a strong sense of inclusion at the institution, are the key factors for successful student retention. The didactic framework can be used to make the expectations to the teacher, the institution, and the students clearer from the get-go, e.g. by being used as a platform for discussion during introductory classes for new students at the start of the first semester.

Currently, an annual pedagogical day is organized for all teachers at the faculty. Using the foundation to facilitate discussions here is a good starting point. Making heads of sections aware of it and giving them easy to use materials for discussing and exchanging ideas at section meetings, also seems like an easy way forward which might lead to broader awareness and strengthened discourse on educational quality. As with the "reform fatigue" there also seems to be a "meeting fatigue" among staff; integrating it into an already existing meeting structure therefore seems like a better way forward than creating additional structures. Neither is such a strategy expected to foster much resistance among teachers.

## **CONCLUSION**

In general, the respondents were aware of the didactic foundation, which is a very important starting point for the use of it. They generally agree with its content and the described elements of "good teaching and learning".

The main barriers for further use of the didactic foundation are lack of resources (a very high load on the academic staff), not enough arenas for discussion of good teaching and learning, and a missing communication strategy.

The purpose of the didactic foundation was to create a dialogue tool for discussing good teaching and learning. Further information is needed to evaluate if it serves its purpose for all stakeholders (management, teachers, and students).

## FINANCIAL SUPPORT ACKNOWLEDGEMENTS

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## BIOGRAPHICAL INFORMATION

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**Geir Egil Dahle Øien** holds an MscEE degree, and a PhD degree in Telecommunications. He became professor at NTNU in 2001, and served as Dean 2009-2019. He managed NTNU's 'Technology Education of the Future' project 2019-2021. Since Jan. 2022 he is back as professor at NTNU's Dept. of Electronic Systems. Geir has extensive experience from periodic supervision of Nordic education institutions' systematic quality work. He served on the board of NORDTEK 2021 – 2023, and led *the Portfolio Board for Enabling Technologies* in The Research Council of Norway 2019 - 2023. In 2022 he was guest researcher at Aarhus University. He currently leads the *Centre for Science and Engineering Education Development* (SEED) at NTNU.

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## Appendix A

In January 2022, the Faculty of Technical Sciences (TECH) established a working group to formulate a didactic foundation for instructional practices. During 2022, the working group held a series of meetings with different stakeholders (teachers, students, educational management, administration) and – by February 2023 – finalized and published “the **TECH didactic foundation**”. The purpose is to support the dialogue about teaching between the three key players:

You can find the didactic foundation here:

[https://kvalitet.au.dk/fileadmin/kvalitetsportal/NAT\\_og\\_TECH/TECH/20230112\\_didactic\\_foundation\\_-\\_EN.pdf](https://kvalitet.au.dk/fileadmin/kvalitetsportal/NAT_og_TECH/TECH/20230112_didactic_foundation_-_EN.pdf)

The following questions evaluate the experience with the didactic foundation so far, and its possible impact.

The results of the evaluation will not be linked to specific persons. The data will be used in aggregated form in a publication.

### What is your role with education at TECH?

- (1)  Vice-Dean for Education/Head of Studies Administration
- (2)  Deputy Head of Department for Education/Educational Responsible
- (3)  Director of Studies
- (4)  Head of Study Program (Uddannelsesansvarlig)
- (5)  Other \_\_\_\_\_

### Are you aware of TECH's didactic foundation?

- (1)  Not at all aware
- (2)  Not aware
- (3)  Somewhat aware
- (4)  Aware
- (5)  Very Aware

### How do you see the usefulness of the didactic foundation?

- (1)  Not at all useful
- (2)  Not Useful
- (3)  Somewhat useful
- (4)  Useful
- (5)  Very useful

### Why did you evaluate the usefulness the way you did?

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**Which specific usages can you see for the didactic foundation?**

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**Are there elements of the didactic foundation that you do NOT understand? Please comment in the text field.**

- (1)  Why the three key players are student, lecturer and institution \_\_\_\_\_
- (2)  One or more of the elements for the student (Engages in own learning, Establishes good conditions for own learning, Contributes to a good learning environment) \_\_\_\_\_
- (3)  One or more of the elements for the lecturer (Has an eye for the student(s), Creates an inspiring learning environment, Demonstrates high subject knowledge, Ensures coherence with other disciplines and society) \_\_\_\_\_
- (4)  One or more of the elements for the institution (Ensures good educational facilities and physical surroundings, Ensures optimal planning, Facilitates co-operation between relevant stakeholders, Ensures opportunities for upgrading of qualifications and competency development) \_\_\_\_\_
- (5)  Other \_\_\_\_\_

**Are there elements of the didactic foundation that you do NOT agree with? Please comment in the text field.**

- (1)  That the three key players are student, lecturer and institution \_\_\_\_\_
- (2)  One or more of the elements for the student (Engages in own learning, Establishes good conditions for own learning, Contributes to a good learning environment) \_\_\_\_\_
- (3)  One or more of the elements for the lecturer (Has an eye for the student(s), Creates an inspiring learning environment, Demonstrates high subject knowledge, Ensures coherence with other disciplines and society) \_\_\_\_\_
- (4)  One or more of the elements for the institution (Ensures good educational facilities and physical surroundings, Ensures optimal planning, Facilitates co-operation between relevant stakeholders, Ensures opportunities for upgrading of qualifications and competency development) \_\_\_\_\_
- (5)  Other \_\_\_\_\_

**Are there elements of the didactic foundation that you have actively used (e.g. in meetings or workshops)? Please comment in the text field.**

- (1)  That the three key players are student, lecturer and institution \_\_\_\_\_
- (2)  One or more of the elements for the student (engages in own learning, establishes good conditions for own learning, Contributes to a good learning environment) \_\_\_\_\_
- (3)  One or more of the elements for the lecturer (Has an eye for the student(s), Creates an inspiring learning environment, Demonstrates high subject knowledge, Ensures coherence with other disciplines and society) \_\_\_\_\_
- (4)  One or more of the elements for the institution (Ensures good educational facilities and physical surroundings, Ensures optimal planning, Facilitates co-operation between relevant stakeholders, Ensures opportunities for upgrading of qualifications and competency development) \_\_\_\_\_
- (5)  Other \_\_\_\_\_

### **If you have actively used the didactic foundation, how have you done it?**

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### **How do you plan to use the didactic foundation?**

- (1)  Resource planning
- (2)  Enhancement of the quality of teaching
- (3)  Enhancement of the quality of the infrastructure and/or facilities
- (9)  Setting goals for educational quality
- (4)  Measurement of the quality of teaching
- (10)  Implementing educational competence development measures
- (5)  In accreditation
- (8)  In communication to e.g. staff or students
- (11)  Creating new arenas or fora for discussing education quality
- (6)  Other \_\_\_\_\_
- (7)  Do not plan to use it

### **What barriers do you see to the use of the didactic framework?**

- (9)  Lack of motivation among faculty
- (11)  Conservative faculty/education culture
- (1)  Lack of resources (time)
- (7)  Lack of resources (money)
- (8)  Lack of resources (people)
- (16)  Lack of resources (learning space)
- (2)  Unclear mandates (who takes the initiative, who has the responsibility for what)
- (3)  Uncertain how to use it/what to use it for in practice
- (4)  No obvious places (e.g. meetings) where to use it

- (10)  Logistical barriers (scheduling of courses, lectures, exams etc)
- (12)  Lack of arenas where the three key players can systematically interact to improve education
- (13)  'Reform fatigue' among employees
- (14)  Lack of management authority and trust among key players
- (15)  Other priorities are currently more important (please specify) \_\_\_\_\_
- (5)  Other \_\_\_\_\_
- (6)  No barriers

**Do you have other comments about the didactic foundation or the questionnaire?**

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# PHILOSOPHY OF ENGINEERING: A MOTIVATION COURSE FOR FRESHMEN ENGINEERING STUDENTS

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## ABSTRACT

All undergraduate engineering curriculum are centred to impart technical skills and knowledge, assess students' ability to apply these skills and knowledge. The curricula lack courses that enlighten the students about engineering occupational categories, desired attributes for each occupation category and enable them to philosophically analyse the nature and impact of these occupations. This void causes lack of motivation among students in learning technical skills and knowledge in general. To address this gap, a mandatory course titled "Philosophy of Engineering" is introduced and offered to freshmen students of all engineering disciplines. This course provides the students a comprehensive outline of engineering, role of engineers, connection between engineer and society, need for conceive, design, implement and operate skills to solve complex industrial or societal problems. The course is delivered by a team of faculty for interdisciplinary engineering students using flexible and student led active learning techniques in every session. As a part of this course, interdisciplinary student groups are formed and given a task to conceive interdisciplinary engineering ideas for solving the local community problems. This activity enabled the students to think critically and creatively during their first year of study. In line with the indented course outcomes and student led learning activities, students also give input on assessment tasks and related assessment criteria. Students feedback on the course is obtained through direct and indirect methods. The students realize it engaging, compelling to learn more on engineering and have given positive feedback on the context and purpose of the course. This paper describes the design and development of this course using ADDIE (Analyse Design Develop Implement and Evaluate) and Understanding by Design (UbD) models.

## KEYWORDS

Philosophy, attributes of engineers, interdisciplinary, sustainable development, Understanding by Design, ADDIE model, Standards: 1, 2, 3, 4, 5, 7, 8, 11, 12

## **INTRODUCTION**

A working group was formed at SRM Institute of Science and Technology (SRMIST) to perform gap analysis in present undergraduate engineering curriculum. In the past, the working group had analysed gaps between desired and actual curriculum to improve student learning outcomes and meet program educational objectives. To fill the gap, new courses were introduced with contemporary discipline specific knowledge and skills for industry and societal needs. This time, before performing curriculum gap analysis, the working group had conducted an exit survey from graduating undergraduate engineering students on curriculum, education in terms of quality and experiences. According to the survey results, about 40 percent of the graduates have mentioned that the existing curriculum lack motivational courses that enlighten them about role of engineers, engineering occupational categories and desired attributes for each occupation category. The working group had identified this void that causes lack of motivation among students in learning technical skills and knowledge in general. To address this gap, a mandatory course titled “Philosophy of Engineering” is introduced and offered to freshmen students of all engineering disciplines. ADDIE model was chosen to Analyse, Design, Develop, Implement and Evaluate this course (Tu, Zhang, & Zhang, 2021). This work addresses CDIO standards 2, 7, 8 and 11 on Learning Outcomes, Integrated Learning Experiences, Active Learning and Learning Assessments.

The structure of this paper is organized as follows: (a) Analysis (b) Design (c) Development (c) Implementation and Evaluation of the course (d) Conclusion.

## **ANALYSIS**

The group analysed various frameworks for designing this course such as Universal Design of Learning (UDL), Integrated Course Design (ICD) and Understanding by Design (UbD) frameworks. The UbD framework recommends that the instructors should focus on the learning outcomes and assessments in line to the outcomes prior to the design of teaching and learning activities (Wiggins & McTighe, 2005). For this reason, the group had considered this UbD approach for designing this course than the traditional approaches. Before designing this course, a comprehensive outline is created as follows: engineering, history of engineering development, role of engineers, engineering occupational categories, desired attributes for each occupation, connection between engineer and society; ontology, epistemology, methodology, axiology of engineering; need for Conceive, Design, Implement and Operate (CDIO) skills to solve complex industrial or societal problems.

## **DESIGN**

Understanding by Design otherwise called as Backward Design framework is typically used for designing curriculum, courses and learning contents in each unit. In contrast to the forward design approach, the backward design approach first considers the learning outcomes of the course which is in compliance with CDIO Standard 2 – Learning Outcomes. These learning outcomes address the knowledge and skills that the students will understand and perform after the completion of the course. Once the learning outcomes are articulated, the second stage focus on design of assessments aligned with learning outcomes. The third stage focus on CDIO standard 8 – Active learning i.e. design of teaching and learning activities for each learning outcomes and assessments considered. The design of this course using backward design approach stage by stage are given in the following sections.

## Stage 1 – Desired Results

In the first stage, learning objectives or rationale of the course is considered. This stage addresses the following three questions: What students should listen, read, visualize and explore? What knowledge and skills should students enhance as a part of CDIO Standard 7 - Integrated Learning Experiences?, What are big concepts and understandings that the students should retain?. Table 1. elaborates the first stage of the UbD process.

Table 1. First Stage – Desired Results

| <b>Established Objectives/Rationale</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ol style="list-style-type: none"> <li>1. Inspire a holistic overview of engineering</li> <li>2. Enlighten the methods and methodologies for building ontologies for systems engineering</li> <li>3. Acquaint with engineering knowledge, building engineering knowledge and value of engineering</li> <li>4. Upskill the engineering design process in aspects of conceive, design, implement and operate methodology</li> <li>5. Instil the role of engineers in society, code of ethics and socio-politics of technology and engineering</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Transfer</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <p><i>Students will be able to independently use their learning to</i></p> <ul style="list-style-type: none"> <li>• Analyse the relation between Arts, Mathematics, Science, Technology and Engineering and desired attributes of an engineer</li> <li>• Build ontologies for systems engineering using concept/mind mapping techniques</li> <li>• Analyse the knowledge base in engineering, distinctive features of engineering design and RIASEC model</li> <li>• Illustrate the engineering design process for the given application, analyse the requirements of CDIO engineers</li> <li>• Evaluate designs on their environmental and societal aspects and do organizational analysis on professional engineering organizations</li> </ul>                                                                                                                                                                                                                                                                                                                 |
| <b>Meaning</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <p><b>UNDERSTANDINGS</b></p> <p><i>Students will understand that</i></p> <ul style="list-style-type: none"> <li>• Engineering has evolved to a new dimension from prehistory to the present situation</li> <li>• Engineering has connection with Arts, Science, Mathematics and Technology</li> <li>• Engineers should possess certain knowledge, skills and attitude that are commonly agreed by many countries in the Washington Accord (International Engineering Alliance, 1869).</li> <li>• Engineers use constructivism and connectivism approach to develop engineering applications</li> <li>• Engineers can play various roles in different fields of engineering</li> <li>• Engineers need to conceive, design, implement and operate engineering systems, processes and products</li> <li>• Engineers should follow ethical code of conduct</li> <li>• Engineers play a vital role on sustainable development</li> <li>• Engineers should be a life-long learner and should take part in professional engineering organisation activities.</li> </ul> |
| <p><b>ESSENTIAL QUESTIONS</b></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><i>Students will keep considering</i></p> <ul style="list-style-type: none"> <li>• Define engineering?</li> <li>• Is arts context necessary for engineering?</li> <li>• Illustrate product life cycle using concept mapping or mind mapping tool.</li> <li>• List out various knowledge base in engineering.</li> <li>• What are the four dimensions of engineering?</li> <li>• Difference between scientific method and engineering design.</li> <li>• List various professional engineering organizations.</li> </ul>                                                                                                                                                                                                                                                                 |
| <p><b>Acquisition of Knowledge and Skills</b></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <p><i>Students will know</i></p> <ul style="list-style-type: none"> <li>• STEAM Pyramid</li> <li>• Desired attributes of an engineer</li> <li>• Engineering habits of mind</li> <li>• Reference ontology and application ontology</li> <li>• Product lifecycle, commodities, services and infrastructure</li> <li>• RIASEC model</li> <li>• Epistemology of engineering design</li> <li>• Rigour, creativity and change in engineering</li> <li>• CDIO methodology</li> </ul>                                                                                                                                                                                                                                                                                                              |
| <p><i>Students will be skilled at</i></p> <ul style="list-style-type: none"> <li>• Reference ontology, engineering application ontology, product life cycle ontology using concept/mind mapping</li> <li>• Case study on RIASEC theory of career choice</li> <li>• Analyse distinctive features of epistemology of engineering design</li> <li>• Conceive engineering ideas for local community problems (conceive skill)</li> <li>• Design, Implement and Operation Process</li> <li>• Illustrate the engineering design process for the given application</li> <li>• Analyse the requirements of operational engineers</li> <li>• Evaluate popular inventions and apply their new point of view to re-design</li> <li>• Case Study on achieving Sustainable Development Goals</li> </ul> |

**Stage 2 – Evidence**

The students' learning is evidenced through appropriate assessments and performance tasks. The second stage of UbD framework consider the above tasks by addressing the following questions: How to know whether the students have achieved the desired results? What evidences are accepted for students understanding and proficiency? Table 2. elaborates the second stage of the UbD process.

Table 2. Second Stage - Evidence

|                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Evaluation Criteria</b></p>                                                                                                                                                                                                                                                                                                                                                                                                          |
| <p><i>Performance Indicators</i></p> <ul style="list-style-type: none"> <li>• For case studies – Uniqueness of the case, analysis/solution options, recommendations, conclusions, presentation skills</li> <li>• For concept/mind mapping – Effective use of tools, no of connections, meaningful links</li> <li>• For case studies on sustainability – Appropriate handprints and footprints of the sustainable goal discussed</li> </ul> |



|                                                                                                                                                                                |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>• For CDIO project – Identification of problem domain/detailed analysis, study of existing problems, feasibility of proposal</li> </ul> |
| <b>Evidences</b>                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>• Quizzes</li> <li>• Case study assignments</li> <li>• Poster presentations</li> <li>• CDIO projects</li> </ul>                         |

### **Stage 3 – Learning Plan**

The final stage of UbD framework consider the teaching strategies and learning activities to be created by addressing the following questions: What knowledge and skills will enable the students to perform effectively and achieve desired results? What type of learning activities will enhance students’ knowledge and skills? What learning materials and resources are to be prepared to attain these objectives? Table 3. elaborates the third stage of the UbD process.

Table 3. Third Stage – Learning Plan

| <b>Summary of Key Learning Events and Instructions</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>In this course BOPPPS model is used to organize the teaching process for each session (Pattison &amp; Day, 2006). The BOPPPS model divides each teaching session in to six stages: Bridge in, Objective, Pre-assessment, Participatory Learning, Post-assessment and Summary.</p> <p><i>Bridge in:</i> This stage is used to attract the attention of students, make them think critically, help them to focus on the topic to be learned. Strategies used in this stage are motivational videos, brainstorming, storytelling.</p> <p><i>Objective:</i> In this stage, student know about the purpose of this session learning and its focus direction.</p> <p><i>Pre-assessment:</i> This stage is to understand the existing knowledge of the students on the topic to be learned and will enable them to construct the knowledge through deep learning. The strategies used are brainstorming, word cloud, quizzes.</p> <p><i>Participatory Learning:</i> This stage brings active participation of the students through learning activities aligned with the intended learning outcomes (Biggs, 2014). The strategies used are inquiry-based learning group discussions, debates, think-pare-share, jigsaw, poster presentation, case study, concept/mind mapping, snowball, worksheet, problem based learning.</p> <p><i>Post-assessment:</i> This stage is to understand whether the students have learned the concept and attained the intended outcomes. The strategies used are quizzes, one minute paper, muddiest point.</p> <p><i>Summary:</i> This stage enables the students to connect learnings and reflect on the learning. The strategies used are recall and review through comments.</p> <p>As a part of this course, interdisciplinary student groups are formed and given a task to conceive interdisciplinary or interdisciplinary engineering ideas for solving the local community problems. This activity enabled the students to think critically and creatively during their first year of study. Only conceive part in the CDIO skill is evaluated in this activity using a grading rubric.</p> |

## **DEVELOPMENT**

In the development stage, all the elements of the course are assembled. The philosophy of engineering course is an integrated 3 credit course with 2 credits for lecture and 1 credit for practice. The total hours of engagement per semester is 60 hours. The course contents and learning activities designed in the design phase are structured session wise to check whether the course can be completed within the scheduled hours of engagement. Once the contents and activities are fit into the structure, learning materials including reading materials, presentations and videos with animations are developed using ICT tools by the subject experts for the learners with different learning styles (Rajeev & Vairavel, 2021). The faculty members at SRMIST are well trained in developing learning materials, instructional strategies and assessments using ICT tools as a part of faculty teaching competency development framework fulfilling CDIO standard 10 – Learning Assessments (Rajeev & Vairavel, 2023). Assessments including quizzes, worksheets, assignment tasks, case studies, topics for groups discussions and debates with evaluation rubrics are prepared for the entire sessions planned. The learning materials and assessment tasks are uploaded in learning management system before the commencement of the learning sessions. The societal problems for conceiving ideas exercise are identified through collaboration with local non-governmental organizations.

## **IMPLEMENTATION AND EVALUATION**

To impart interdisciplinary learning from first year onwards, students from all the engineering disciplines in equal are assigned in each class of size 40. The course is delivered by a team of faculty (two per class) for interdisciplinary engineering students using flexible and student led active learning techniques in every session. Students also decide the assessment tasks, and corresponding assessment criteria. Even though BOPPPS model is adopted for all the sessions, activities in the stages of the model are led by the students. Due to student-led-activities in most of the sessions, the expected plan for a week may slightly vary and is covered in the forthcoming weeks with the knowledge of students. A keen focus has been kept on the activities that engages students to think critically and enquire philosophically.

Inculcating concepts related to the philosophical aspects of engineering such as ontology, epistemology, methodology and axiology helped the students to think critically and enquire philosophically the scope and purpose of engineering. The entire course is centred on the concept of engineers and the society and most interesting part in the course as per the students' feedback is historical development of engineering in solving societal needs. Students have raised more questions philosophically and shown interest to develop more engineering applications for the benefit of the society. Interdisciplinary engagement in the class enabled the students to understand the diverse nature of engineering and opened up interesting discussions on interdisciplinary project ideas inside the classroom.

The learning experiences shared by the freshmen engineering students of strength 5000 are really encouraging. The summary of the feedback given by the students in the mid of the semester is shown in Figure 1. The performance indicators considered for feedback analysis are course content (whether its inspiring to pursue engineering), student-led-activities approach, solving societal problems, assessment and evaluation methods. The analysis shows that more than 70 percent of the students are highly motivated through this course to pursue engineering with clear idea. With respect to student-led activities, 30 percent of the students have given excellent, and 40 percent have given very good, this is due to the time consumed in preferring the activities and deviation in the learning plan. This student-led

approach will be improved with proper planning in advance of each session. Almost 70 percent of the students could conceive ideas for the societal problems through scaffolding and only 15 percent could solve independently without guidance. Being a freshmen student, this result was expected earlier and students now have clear idea about conceiving ideas for the problems in the future. Above 80 percent have given excellent for assessment and evaluation methods used which will be improved further by including more varieties of assessments in the upcoming sessions.

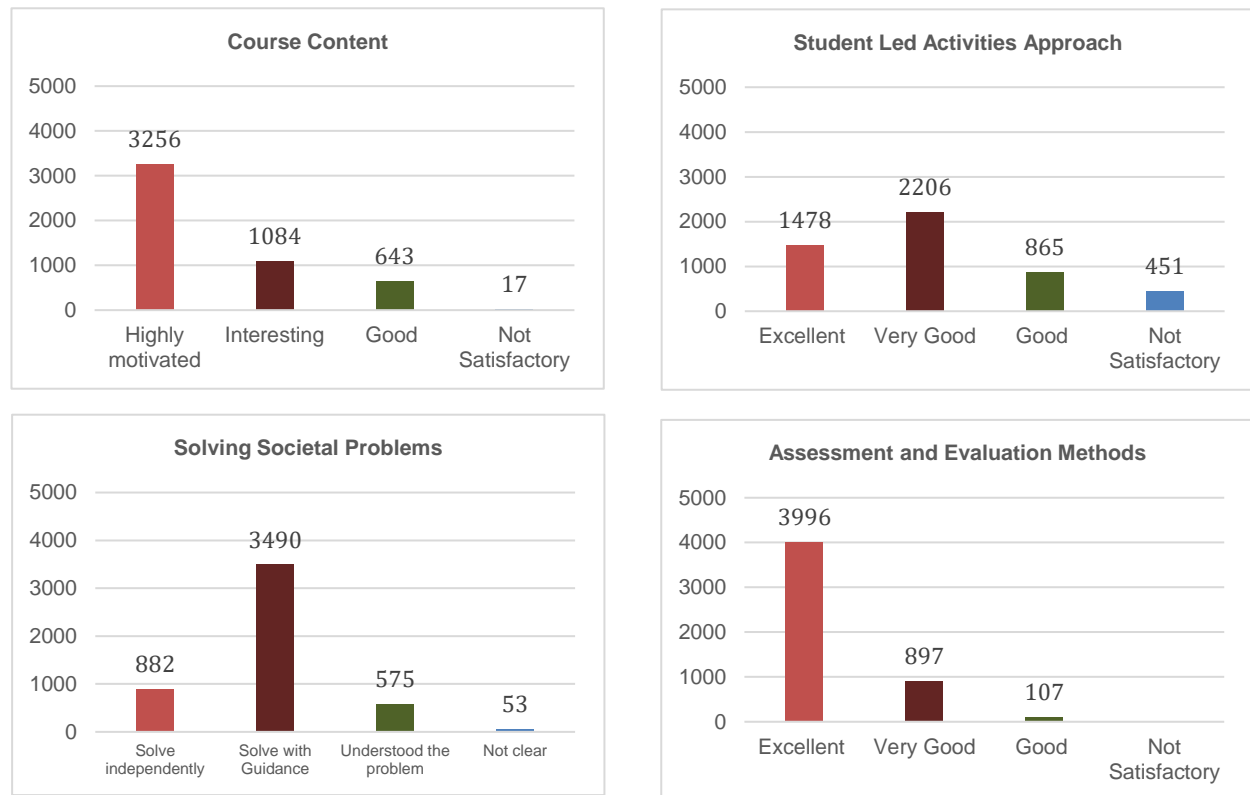


Figure 1. Feedback Analysis

## CONCLUSION

This paper gives a detailed need analysis, design, development, implementation and evaluation of a new course titled philosophy of engineering for all freshmen undergraduate engineering students. Students find this course highly motivational towards engineering and pursue engineering program with clear idea. Upon successful completion of this course, the freshmen students gain deep insight on engineering, role of engineers and their desired attributes, connection between engineer and society; ontology, epistemology, methodology, axiology of engineering; need for Conceive, Design, Implement and Operate (CDIO) skills to solve complex engineering problems. The course also enhances critical thinking, creative thinking skills, philosophical enquiry and engineering mindset among the students with quest to solve societal problems using ethical standards and sustainable development methods. As a part of continuous improvement of the course, student-led approach and other areas of improvement will be identified and augmented in the future.

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# AN INTERNATIONAL UNIVERSITY PERSPECTIVE ON BARRIERS AND ENABLERS FOR LIFELONG LEARNING IN ENGINEERING

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## ABSTRACT

This paper extends the use of a framework identifying four types of barriers to lifelong learning (LLL): institutional, situational, dispositional, and informational. Initially applied to Nordic universities, the framework is now used to interview a broader set of international stakeholders about LLL provisioning. The study explores commonalities and differences across regions, and the framework's potential to highlight key barriers and enablers, informing strategic and policy changes. The countries involved are Denmark, Norway, Finland, The Netherlands, and Singapore. Following the description from each country, it identifies institutional, situational, dispositional, and informational barriers, which are interrelated and influence LLL in an international context. Challenges include funding, balancing job and family commitments, and the need for a learner-centric approach. The study reveals that LLL plays a minor role in universities, with insufficient encouragement despite being included in strategies. Major obstacles include restrictive legislation, bureaucratic boundaries, and unstable funding models. Overcoming these could enable nationwide or transnational platforms for LLL.

## KEYWORDS

Lifelong learning, framework evaluation, enablers and barriers for lifelong learning, Standards: 2, 3, 9, 10

## INTRODUCTION

Lifelong learning (LLL) is a political priority in most parts of the world, focusing on workforce upskilling and reskilling to enhance national competitiveness and productivity. Universities are expected to play a central role in leveraging LLL, but they often struggle to establish sustainable models due to challenges, e.g., economic unpredictability, resource scarcity, market understanding, academic capacity, and motivation. LLL also plays a role for the CDIO Initiative ([www.cdio.org](http://www.cdio.org)), with a focus on the ability of a learner to learn through life.

## FRAMEWORK FOR BARRIERS AND ENABLERS FOR LLL

Previous studies have shown that barriers that influence the behaviour of lifelong learners can be broadly characterised along four different axes (Cross, 1981, Darkenwald and Merriam, 1982). Moreover, recent work by Bennedsen and Øien (2023) has indicated that the same four classes of barriers are highly relevant for understanding the challenges of educational institutions when it comes to LLL provisioning. They are:

- **Institutional** (or structural) barriers – institutional, political, or structural practices and procedures that may discourage or prevent either learners' participation or universities' provision of LLL offerings.
- **Situational** barriers – practical barriers which arise due to a person's life situation at given points in his or her family or working life cycle.
- **Dispositional** barriers – personality traits or personal qualities which influence a person's intrinsic motivation to engage in LLL.
- **Information** barriers – referring to the (lack of) availability and awareness of information regarding LLL opportunities.

Bennedsen and Øien used these four axes as a framework to interview Nordic university stakeholders on their views, experiences, and strategies on LLL, thereby both collecting information about the state of LLL in the Nordics, as well as evaluating the usefulness of the framework as a tool for analysing Nordic and Baltic universities' strategies and priorities regarding LLL (Bennedsen and Øien, 2023). In this work, the use of the framework was also expanded to not only discuss barriers but also uncover potential *enablers and opportunities* characterized along those same four axes. The work started at the CDIO conference in 2023 as a working group.

This paper expands the geographical boundaries of the evaluation of the above framework from Nordic countries (with very similar cultures and educational systems) to a broader context. This is done by using the framework to interview stakeholders at international CDIO member universities involved in LLL about barriers and enablers experienced in their work on LLL provisioning. Afterwards, the results are used to reflect on the framework's usefulness regarding barriers and enablers for LLL. Common denominators, similarities, and differences across country borders and continents are discussed. The usefulness lies in the systematic insight into root causes and important levers such a framework can provide, potentially pointing to strategy and policy changes that may serve to lower the most important barriers and exploit the most important enablers.

## RESEARCH DESIGN

To gain a more international perspective, semi-structured interviews are carried out with relevant stakeholders at six universities in five countries: Singapore, The Netherlands, Finland, Norway, and Denmark. At each university, the authors selected persons to interview. The selection was based on the authors' personal connections and knowledge of the “right” person to interview.

Table 1. Number of interviewee(s) and their roles for each country.

| Country         | Interviewee(s) | Roles                                                                                                                                                  |
|-----------------|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| Denmark         | two            | teacher, administrative                                                                                                                                |
| Finland         | one            | administrative/manager                                                                                                                                 |
| The Netherlands | four           | professor, director, manager (nationwide), researcher                                                                                                  |
| Norway          | two            | head of an engineering department, administrative manager of a lifelong learning support unit                                                          |
| Singapore       | four           | program owner (also doing teaching), administrator seeking personal upgrading, academic director, manager (involved in teaching and managing a course) |

The respondents received this message before the interview:

*The focus of this interview is Lifelong Learning (LLL). It is done as one out of a series of interviews for a newly established working group within the international CDIO network trying to obtain more insight into barriers and enablers for university-level lifelong learning as seen from an education provider's perspective, with an emphasis on the engineering field. LLL is a broad term that presents a challenge when it comes to defining it in a specific manner. Its association with other similar concepts, including but not limited to lifelong education, permanent education, recurrent education, continuing education, adult education, learning organizations, and the learning society (a society where learning is all-encompassing), adds to this difficulty. In this interview, I will have a narrower focus, on formal learning taking place after a learner's initial education and offered as credit-giving activities by our institution. It will be done in English to enable sharing of good practices, showstoppers etc.*

The interviews were semi-structured with the following headlines:

- **Background information:** Personal and institutional background.
- **Context:** What is the main focus of the organization with respect to LLL
- Short introduction of the framework (the four dimensions)
- **Institutional barriers and enablers:** The most prominent institutional barriers and enablers, as seen from the institutional and learners' side?



- **Situational barriers and enablers:** The most prominent situational barriers and enablers, as seen from the institutional and learners' side?
- **Dispositional barriers and enablers:** The most prominent dispositional barriers and enablers, as seen from the institutional and learners' side?
- **Information barriers and enablers:** The most prominent informational barriers and enablers, as seen from the institutional and learners' side?
- **Additional comments:** Are there other aspects of enablers and/or barriers that we have not talked about so far – if so, which? Did the categories we defined here help you to think about LLL – why or why not?

The interviews were recorded, and notes were taken during the interview. The notes were used as pointers in the interviews to find relevant points of interest.

The analysis was done in the following order:

1. After the interviews, one of the paper authors generalized the findings of the specific country, structured around the four axes.
2. A “harmonizing phase” was done to balance the descriptions from the different countries.
3. All descriptions were considered carefully, and commonalities were noted.
4. The commonalities were generalized into the four areas by a pair of authors.

In the following sections the generalized results of the interviews per country are briefly introduced and discussed. In the discussion and conclusion section of this paper the international commonalities regarding the LLL barriers and enablers are stated.

## DENMARK

In Denmark, like in many other countries, universities are state-run and financed. Part of university's funding is based on the number of credit hours a student “earns”. “Traditional” (i.e. full-time) university educations are “free”, LLL has some participant payment and some payment from the state. Some state institutions (like IT-vest) support LLL (gives the universities support for development and operation).

LLL at universities are accredited like all other educational offerings. It is, at the university level, typically implemented as a part-time degree (a master's degree consisting of 60 ECTS (= one year of full-time studies) done as part-time). In many cases, it is expected that the students take the entire programme, but there are also examples of programmes where the students can take parts of a programme (the smallest element is typically 5 ECTS). Universities can make commercial courses (but need to be on “fairgrounds”).

The data gathering is based on interviews with two persons from Aarhus University (AU) – one administrative and one “teacher”. The administrative person has been at the university for more than 10 years (and before that also been involved in LLL). She has been working with enrolment, marketing, internal processes and accreditation of LLL at AU. The other interviewee is an associate professor at the Department of Computer Science. He has been teaching LLL for the last 10+ years and he is THE “LLL teaching” person at the department.

In general, both interviewed persons found the framework useful and understandable since it gave structure to the interview and the dimensions made sense.

Institutional: The provision of LLL does not have a high priority at the University of Aarhus. In the strategy for 2025, it is stated:

*“Sub-goal – Development of the continuing and further education of the future: The university’s goal is to contribute to meeting society’s increasing demand for the continuing education of the workforce through research-based further and continuing education, for example in connection with the increased digitalization of society. The existing continuing and further education models are currently under pressure. To this end, the university wants to work with new models that can meet the need for new competencies on the part of both graduates and the labour market, now and in future.”*

There has been an effort to make it attractive for the teachers to develop new formats of education from top management using incentives like financial support for development, extra salary, and administrative support when courses are “for sale”. From the teaching side, there is an acceptance that the associate professor uses his resources on LLL (checkbox is marked by the management) but not much focus. Other teachers are NOT interested in LLL, it does not give them the possibility to expand their research group by “picking” new PhD students.

Situational: Both interviewees stress that the learners are often people with busy jobs, family etc. The students struggle with finding time to do their LLL, and the employer typically pays and allows for the student to take one or two days of class hours per month but nothing more (the typical workload for a LLL student is 15 ECTS per 9 months; the legislation focus on students who will study for a full master’s degree).

The main motivation for the learners is to gain new knowledge that can be applied in their job directly. This is done by, for instance, actual written tasks that use “data” from their daily job. It is also important to offer the possibility of online courses in combination with physical meetings and networking with the other participants, teachers and researchers.

Dispositional: Education takes time, and it is important that the employer is engaged in the learner’s participation in further education and that there are clear conditions and agreements about this. The funding of education is also important – is it financed by the employer or by the employee? What kind of funding is available? In Denmark, there is national funding e.g., “Omstillingsfonden” but that is mostly for public employed persons - and something that was negotiated during the general payment negotiations.

Informational: At Aarhus University there is a central website, which offers information on all kinds of LLL, but in general not much is done on a central level. A national, official website exists with all Danish universities’ offerings; the “feeling” is that not a lot of potential learners know/use it to search for possible LLL offerings. The individual departments make promotions of the specific offers e.g., an MBA for company CEOs, but there is no central marketing or promotions for e.g. specially chosen and relevant target groups. One such example is the promotion of industry related conferences.

The use of alumni as a target group is relevant and recently, a survey among the alumni has been deployed to investigate the needs, wishes and conditions for participation in LLL. A closer cooperation and dialogue with employers’ organizations and with relevant unions could strengthen the knowledge of the customers’ needs.

## FINLAND

Different aspects of continuous and lifelong learning are being widely discussed also in Finland. A new National Higher Education Strategy for Lifelong Learning was published in December 2022 (Ministry of Education and Culture Finland, 2022). The strategy aims at strengthening and clarifying the role of higher education institutions as providers of different types of courses and activities contributing to the life-wide competence development of both individuals as well as to the further development of different organizations.

According to Eurostat (2022), adults in the Nordic countries participate in education and training rather actively compared to the EU average. There is, for instance, a long tradition of offering university courses to adult learners via the so-called open university concept in Finland. There are national plans to change the funding model of LLL in the future, but most of the costs are currently covered by state funding, which enables competence development at a very reasonable price. However, participation in these courses is strongly connected to the field of profession and, especially, Engineering and Science professionals are underrepresented. The universities are not playing a major role in the LLL efforts in this domain.

The framework for barriers and enablers for LLL in the Finnish context was tested only with one interviewee who had been working a long time in the field of adult education. The concepts and details of the framework were easy to understand, perhaps partly because of the background of the respondent. Nevertheless, the framework provided added value to the discussion and facilitated a deeper analysis of the different perspectives. Especially in the field of Engineering, there is a need to define and redefine LLL in the higher education context, and the framework may provide a useful tool to guide the way and to create common ground between the different actors.

Institutional: According to the interviewee, the most crucial institutional issue in terms of both barriers and enablers relates to finance. Very few participant groups have neither the ability nor the motivation to pay the real expenses of what a course or programme costs to deliver. That is, the funding issue needs to be resolved for the LLL to be viable. Another institutional barrier is that there is, after all, surprisingly little cooperation between traditional degree-oriented education programs and education/training aimed at those active in working life.

Situational: Flexibility in terms of time aspects and scheduling of training programmes was mentioned as an important situational enabler. That is, it is important to find flexible study arrangements, such as combining education and work in terms of time with flexible distance learning solutions.

Dispositional: However, the interviewee was not convinced that the question about dispositional barriers and enablers is as relevant a question in terms of LLL as the other aspects. Personal characteristics and qualities as obstacles and enablers seem, according to his/her opinion, not to have the same importance in the discussion about LLL.

Informational: Efficient exchange of information is highly important, particularly in terms of recruitment to different LLL courses and programmes, but also in terms of the organisation and implementation of studies. Guidance and counselling services should undoubtedly be further developed. Creating psychologically safe conditions for study paths for adult learners is a key issue. This is probably most effectively achieved through clear communication and good information.

Finally, the interviewee concluded that “Lifelong and continuous learning have been national battle cries for many years, and it is depressing how little progress has been made and how few well-functioning models have been developed and tested.” More creative models should be courageously piloted. Such experimentation could be carried out within international cooperation.

## **THE NETHERLANDS**

Four representatives have been interviewed for this research: First, the professor from the research group “Innovative and effective education” and academic director of Master Educational Leadership. Second, the managing director of the National Program-team LLL and former academic director of Saxion Parttime School. Third, the academic director of Life Science, Engineering & Design. And last, a Human Capital researcher from TechYourFuture and research group Employability Transition.

The results show the multifaceted landscape of Lifelong Learning (LLL) development in the Netherlands, particularly within Saxion University of Applied Sciences, offering a nuanced understanding of challenges and successes in educational innovation. The results identify three layers of LLL development, starting with the recognition of the need for change and a shift towards prioritizing learning activities over traditional education. The second layer emphasizes innovation and new perspectives, while the third layer underscores collaboration and the emergence of key skills regionally.

Despite LLL being a longstanding presence in Dutch educational discussions, progress has been moderate, with some initiatives at Saxion facing challenges such as inappropriate products and overestimation of employee interest. The involvement of key figures from the business community is highlighted as crucial for success in LLL initiatives. Learning Communities (LCs) are discussed as hubs fostering interdisciplinary collaboration and seamless learning experiences (Gelten, 2023). The definition of LLL encompasses continuous skill development, seizing growth opportunities, and making informed career shifts.

Successful LLL activities at Saxion include the Part-time School for formal training, the Academy for employees, and the Community of Practice for informal learning. The structured nature and flexibility of these initiatives contribute to their success. Examples like the Smart Solutions Semester, a multidisciplinary assignment with the business community, demonstrate effective engagement. However, challenges exist, such as unclear expectations and varying student motivations.

Institutional barriers include the absence of legal mandates, funding issues, and bureaucratic complexities. The importance of abolishing training course licenses for flexibility and fostering collaboration with companies is emphasized.

Situational barriers for learners involve time constraints, while institutional challenges include coordinating learning paths and addressing the need for flexible start times. Solutions include offering sub-modules and customization to accommodate individual responses to life changes.

Dispositional barriers encompass feedback literacy and the traditional mindset of educators. The importance of a shift towards a coaching role in personal learning paths is highlighted.

Informational barriers involve prescribed rules, lack of transparency, and competition between programs. The proposed solution is a centralized information point and proactive engagement to showcase opportunities directly to companies.

In conclusion, the study advocates for collaboration, forward-thinking approaches, and tailored learning experiences in the development of LLL. Flexibility, regional needs assessments, and increased awareness through active engagement with the professional field are crucial. The results provide valuable insights into the barriers and enablers of the different areas within LLL, emphasizing the need for flexibility in accredited education, transparent information, and a departure from traditional views of companies through joint development of LLL activities for further and better development of LLL in the Netherlands.

## **NORWAY**

Two representatives from NTNU, Norway's largest university, were interviewed. One has a faculty and leadership background and has been involved in continuing and further education within cyber security for almost 20 years. The other interviewee works in NTNU's Continuing Education Department and has been working with continuing and further education from an administrative perspective for more than 20 years.

Institutional: Among the institutional barriers mentioned by the interviewees, the following is seen as the most important from the provider's point of view: the university's main focus is on regular degree education, so the organization is not dimensioned for LLL – there is a lack of both organizational capacity and of institutional economic incentives. Moreover, perceived market uncertainties, regulatory complexities, and a possible lack of organizational adaptability (agility) also complicate the work on LLL provisioning. From the learners' perspective, market aspects also yield complex differences in financial models that can be hard to understand. Industry is also often pushed for time, making continuing and further education hard to prioritize.

Situational: The situational barriers mentioned from the provider's perspective are most often: individual professors lack time and are not personally incentivized to do LLL. Moreover, some professors see the mixing of mature and regular students in the same class as a pedagogical challenge. When it comes to hybrid online - campus teaching (which may be of interest due to the flexibility this offers for learners), many professors also fear that the learning environment may suffer if some students only participate online and are demotivated by this. Taking the individual learner's perspective, the interviewees' experience was that many find it tough juggling work, studies, family time, and spare time. Also, the experience is that individual employers experiencing an economic downturn can't afford to send people – while if a company's economy is good, employees often don't have time to participate in continuing and further education.

Dispositional: Regarding dispositional barriers, the fact that many teachers feel pedagogically challenged when facing mature students, is something that pushes them out of their comfort zone. This can be detrimental to teachers' motivation. The experience is also that some of the more academically inclined teachers see LLL as an 'academic downgrade'. In sum, these factors contribute to the fact that many teachers prefer to spend their time on research and on regular degree education rather than in LLL provisioning.

Informational: The interviewees see the following as the most important information-related barriers from the provider's point of view: The university is not currently tuned to find ways to understand and reach out to the market. Also, for engineering specializations in particular, it can be hard to find interested learners and match them with specific themes/courses that may be relevant for them. Similarly, from the individual learner's perspective, it can be challenging for people to find 'the right course for me', since the university's menu of courses is so broad.

Regarding the use of the 'institutional – situational - dispositional – information-related' framework as a scaffolding tool during interviews, the interviewees responded that the framework is useful. However, 'study environment' is missed as a more explicit topic.

Finally, the interviewees pointed out that transnational collaboration on LLL to alleviate some of the barriers mentioned may be challenging, due to differences in e.g., terminology, requirements, funding models, and regulatory aspects.

## **SINGAPORE**

Using the suggested framework proved to be very useful for both interviewers and interviewees, as it provided guidance in a structured manner. The framework also helped the authors in organizing the results and reporting in the reflections. The following narratives summarize the results, in accordance with the four dimensions of the framework.

Institutional: The effort towards lifelong learning is largely driven by the Singapore Government, under its SkillsFuture Singapore Initiative (<https://www.skillsfuture.gov.sg/>). For academics, the faculty can also upgrade themselves using funding allocated by the Ministry of Education. One can say that it had been institutionalized for the polytechnics. From the budget perspective, these are strong enablers, especially in programs related to improving teaching and learning (T&L), which often is free, if offered within the institution by its T&L Unit. However, the budget is still insufficient for technical or professional causes, and this is the area where most complaints were heard, and where significant justifications are needed. There is also a requirement for faculty to fulfil a minimum of training hours every year (100 hours), but the budgetary constraints meant that most faculty strived to meet the hours by opting for the free T&L programs, and still felt inadequate professionally. One even opined the irony of the very same system that was to be the enabler is also the barrier to LLL.

Situational: The main challenge appears to be timing, especially when it relates to the faculty's current stage of a career. A person rising the rank may be more preoccupied with addressing work challenges and portraying a favourable impression among superiors and put LLL in the backseat. On the other hand, one who is starting a family during mid-career, or caring for ageing parents will likewise sacrifice career development. This is seen in colleagues who opted for no-pay leave to focus on family matters, or some who opted for transfer for non-teaching administrative job functions for "more stable" working hours, pointing to the white elephant in the room that academics often work long hours. On the part of the Singapore Government, much effort has been expended towards addressing the challenge posed by balancing professional development and raising a family, and numerous schemes are available; especially with the help of technologies, e.g. bite-size podcasts, to company "day release" schemes.

Dispositional: The Singapore Government again is leading the effort to encourage its citizens to continually upgrade themselves, especially in today's digital age. Dispositional barriers, much like situational barriers, are a very personal matter influencing one's commitment towards LLL. In Singapore's context, one is quite open to the idea of LLL, given the recognition that most citizens understand that human resources are the country's only competitive asset. However, this often conflicts with the human longing for another pursuit in life as one approaches retirement age. One may not be constrained by a fixed mindset per se ("I am too old for this.") but fell "entitled" to "slower-pace to enjoy one's fruits of labour from earlier efforts". It can be cognitive dissonant when one is told that "there are still new challenges ahead" and to see the retirement age extended; at a time when one would long for the more leisurely lifestyle observed in one's parents.

Informational: It can be said that, at least in Singapore, there is information overload on LLL for potential learners. There are various programs offered by many approved training organizations (ATOs) which include educational institutions and private-sector training providers. It is a case of too many ATOs that had jumped into the "LLL bandwagon", offering a plethora of virtually indistinguishable, "me too" courses, especially those revolving around self-improvement, office productivity, "Management 101", etc; often heavily subsidized under the SkillsFuture Singapore Initiative. There is a lack of professional (technical) programs from ATOs. There are also too many generalities and insufficient clarity, for example on specific requirements, eligibility criteria, and application processes for lifelong learning programs. One consequence is that despite the high level of awareness of the need for LLL, the utilization of SkillsFuture credits for the courses remained low: only 38.8 percent of the eligible individuals aged between 30 and 39 have utilized their credits (CNA, 2023). Again, the enabler had become the barrier.

## **DISCUSSION AND GENERALIZATIONS OF THE EVALUATION IN THE COUNTRIES**

The four barriers – institutional, situational, dispositional, and informational – are not mutually exclusive, i.e. they influence one another. Funding remains a common institutional challenge to all, which has to be negotiated against situational factors and mediated by dispositional ones. Balancing job demands and family commitment against LLL is a common thread. In addition, there is a greater need to tackle the LLL challenges from the perspective of the learners, not just "top-down", and also take into consideration these enablers and barriers in a holistic, integrative manner. Connecting what was learned at LLL to the job role is important. The common challenge here is LLL in a professional (technical) nature, which often faces high financial barriers. The duality of demand on an academic staff to become both solidly grounded in a technical discipline and well-versed in teaching and learning practices, often led to a "training budget paradox<sup>1</sup>". It is already very challenging for faculties to continue developing domain mastery and developing competencies in imparting certain skills and/or attitudes.

At the universities covered in this study, LLL still plays a relatively minor role. Most have LLL included in their strategy, but it is in most cases insufficiently encouraged. The countries have all started to focus on LLL, with Singapore as the one with actions on both strategic, tactical and operational levels. In Europe, the focus is more on political statements whereas the actual operational implementation is often not in place. From the viewpoint of the individual professor, LLL is not seen as something that promotes their career - there is thus a need to expand the focus beyond research as the most dominant indicator for success if LLL is to be strengthened.

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<sup>1</sup>budget insufficient for technical PD but more than enough for T&L PD

**Error! Reference source not found.2.** Condensation of the findings from each country.

|                 | Institutional                                                                                                                                                                                            | Situational                                                                                                                                                                                                                 | Dispositional                                                                                                                                                                                    | Informational                                                                                                                                                                            | Country summary                                                                                                                                                                                                                          |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Denmark         | Very little strategic focus. Funding almost 100% dependent on number of attendees.                                                                                                                       | The students struggle with finding time to learn. Learning typically done in spare-time.                                                                                                                                    | Typically paid by the employer. Some funding schemes for groups of employees (part of the agreement).                                                                                            | Central university and a central national website with all offerings. Very little “push” marketing.                                                                                      | Clearer and more central role of LLL at the universities needed. Longer lasting funding model needed. Better and more targeted marketing.                                                                                                |
| Finland         | Funding needs to be resolved for the LLL to be viable. There are limited connections between degree education/ faculty and offerings aimed at LLL audience.                                              | Finding proper arrangements in terms of time, place and flexible distance learning solutions is vital.                                                                                                                      | This aspect is not considered to be as relevant as the other aspects – at least when it comes to those individuals who are motivated to develop their competences.                               | The university is not tuned to find ways to understand and reach out to the market. It is hard to match the learners with relevant LLL-offerings and vice versa.                         | Funding, flexibility in learning methods and arrangements, better match between needs and offerings, clearer role of LLL in universities.                                                                                                |
| The Netherlands | Institutions need flexibility for lifelong learning, but there is a mismatch in module registration. Main barriers are legal, customization, funding, and record-keeping.                                | Tailored adult education, accommodating personal circumstances. Main obstacles are time, engagement, logistics, cultural differences. Focus on flexible delivery methods and support.                                       | More focus on mindset, adaptability, and collaboration. Main challenges are balancing work-life, embracing change, teacher's role shift. Feedback literacy can influence collaborative learning. | Inconsistent rules hinder part-time courses. Lack of transparency in knowledge institutions. LLL should meet regional needs without competition.                                         | Flexibility, regional needs assessments, and increased awareness through active engagement with the professional field are crucial.                                                                                                      |
| Norway          | Lack of capacity and economic incentives for universities. Market uncertainties, regulatory complexities, and lacking organizational agility. Industry pushed for time; employee LLL hard to prioritize. | Professors lack time and personal incentives. Pedagogical and learning environmental challenges. Tough for learners to juggle work, studies, and personal life. In bad times employers can't afford LLL time for employees. | Teachers pedagogically challenged when facing mature students - pushed out of their comfort zone. Academically inclined teachers may see LLL as an 'academic downgrade'.                         | University not tuned to understand and reach out to market. Hard to find interested learners and match them with specific themes/courses - and for learners to find the 'right' courses. | Current university organization, recruitment, and funding models not well adapted to LLL needs. Lack of capacity, time, and incentives for university professors to engage in LLL. Information barriers both for providers and learners. |
| Singapore       | Funding of deep technical learning still inadequate, while that for T&L are adequately handled within an institution.                                                                                    | Starting a family or caring for aging parents is prioritized over advancing one's career.                                                                                                                                   | Dilemma of “postponing” one's retirement in view of new challenges, cannot afford to “slow down”.                                                                                                | Case of too much information, lack of clarity among many training providers with similar contents.                                                                                       | Support of upgrading of technical nature often focused on helping one to move into new growth area.                                                                                                                                      |



## CONCLUSIONS

The used four-dimensional framework seems to provide a rather well-functioning tool to analyse the LLL conditions in different countries and provide ground for mutual understanding of the different aspects of it. It gave a good structure for the interviews and provided ground for mutual understanding of the different aspects of LLL.

The four barriers – institutional, situational, dispositional, and informational – are not mutually exclusive, i.e. they influence one another but serve as different lenses useful in observing and analysing LLL. Not many additions to the framework were suggested, but one interviewee missed “study environment” as a focus point: LLL is often seen as something that provides the students new networks, a chance to discuss their problems with peers, not necessarily something that they can do in the normal professional setting. From the teacher side, the more mature students give the teacher a unique opportunity to have an applied focus on their research (and establish research collaborations between companies and the university), but also new pedagogical challenges.

From the interviews, the major obstacles that withhold LLL from expanding at university level in all the five countries covered by our study seem to be:

- Universities are restricted by current legislation and capacity constraints in offering education outside the conventional frameworks.
- Bureaucratic boundaries within the knowledge institutes tends to slow down and frustrate LLL initiatives.
- The current funding models are unstable and provide few strong incentives for universities and staff to do LLL.

If these obstacles can be solved, there might be good chances of combining LLL activities from different knowledge institutes nationwide, or even developing a nationwide or even transnational platform for both educational providers and participants.

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# ENGINEERING EDUCATION IN THE ERA OF GLOBAL RESPONSIBILITY

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## ABSTRACT

The United Nations Sustainable Development Goals (UN SDGs) offer a framework for addressing global challenges. To contribute to these goals, engineers need a range of competencies, including technical skills, effective communication, and critical thinking. We suggest using the SDGs as an integrating theme in engineering programs, unifying various modules into a cohesive, multidisciplinary curriculum. The interdisciplinary nature of engineering makes it suitable for such integration. Achieving clean water and sanitation (SDG 6), for example, requires expertise in fluid mechanics and skills in communicating solutions to stakeholders. Ensuring access to affordable and sustainable energy (SDG 7) demands an understanding of energy systems and an ability to evaluate societal and environmental impacts. The SDGs can act as a unifying thread, linking subjects and skills in a way that reflects the real-world complexities engineers face. By integrating these goals into the curriculum, we address the concerns and interests of younger generations who are deeply concerned about environmental issues and the future of the planet. This approach also helps students to understand the interplay of technical, ethical, social, and environmental factors in creating sustainable solutions. In this paper, we propose a straightforward method for constructing engineering curricula that use the Sustainable Development Goals (SDGs) as a guiding thread. We'll apply this method not just to cross-disciplinary or specialised modules but also to basic courses like maths, physics, and algorithmic. Our goal is for students to see that these fundamental subjects are key to tackling environmental problems around the world. Integrating the SDGs can also invigorate teaching methods, promoting active learning and critical reflection. Project-based assignments on SDG challenges enable students to develop technical and interpersonal skills, preparing them as competent engineers and global changemakers, while also resonating with their desire to engage in work that contributes to sustainable and ethical development.

## KEYWORDS

UN SDGs, Engineering Education, Multidisciplinary Skills, Integrated Curriculum, CDIO Standards: 1, 2, 3, 4, 7, 9, 11.

## **INTRODUCTION**

The Intergovernmental Panel on Climate Change's (IPCC, 2023) Sixth Assessment Report (AR6) provides a comprehensive synthesis of current knowledge on climate change, its widespread impacts, and the necessary mitigation and adaptation strategies. The report emphasises the interdependence of climate, ecosystems, biodiversity, and human societies, highlighting the essential role of diverse forms of knowledge and the importance of various actors in climate action. It underscores the unequivocal impact of human activities, particularly greenhouse gas emissions, on global warming, with a significant rise in global surface temperature and a continuous increase in greenhouse gas emissions due to unsustainable practices. A critical aspect of this global challenge is its impact on food and water security, impeding efforts to meet Sustainable Development Goals. While overall agricultural productivity has increased, climate change has decelerated this growth over the past 50 years (IPCC, 2023). In response to these challenges, adaptation planning and implementation have made progress in various sectors and regions, demonstrating benefits and varying effectiveness. Despite this progress, significant adaptation gaps persist and are expected to grow if current implementation rates continue. In an era marked by unprecedented global challenges, ranging from climate change to resource scarcity, the role of engineering in shaping a sustainable future has never been more critical. The UN defines Sustainable Development (SD) as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987). The Sustainable Development Goals (SDGs), a set of 17 interconnected objectives, outline a universal call to action to protect the planet, ensure prosperity, and promote peace and equity. These goals provide a comprehensive roadmap for addressing the most pressing issues of the 21st century. Engineering education, traditionally grounded in technical expertise, must evolve to encompass a broader understanding of the complex, interrelated social and environmental factors that define modern engineering challenges. This development requires a significant change in educational approaches, focusing on training engineers to be technically skilled and capable of contributing responsibly to sustainable development. Given this context, it is essential to urgently adapt engineering education. Engineering disciplines must evolve to incorporate an understanding of climate change impacts and adaptation strategies, equipping future engineers with the knowledge and skills to contribute effectively to addressing these global challenges. Incorporating sustainability, environmental management and social awareness into engineering curricula is crucial. This approach equips engineers to tackle sustainable development goals such as reducing inequalities, preserving biodiversity, combatting hunger and conserving water. This shift in engineering education is a moral obligation to promote a sustainable and equitable future for all. The paper recommends a substantial reshaping of the engineering curriculum. This reshaping involves centering the curriculum around the Sustainable Development Goals (SDGs), which encompass a wide range of issues. The intention is to build the engineering curriculum upon these goals.

## **ENGINEERING EDUCATION FOR SUSTAINABLE DEVELOPMENT**

In 2004, the 2nd International Conference on Engineering Education for Sustainable Development issued the EESD Barcelona Declaration, urging engineering educators to train engineers with an expansive comprehension of complex issues, guided by long-term systemic thinking and ethical considerations in decision-making (EESD Barcelona Declaration (Final Version, October 2004)). This declaration has significantly influenced subsequent conference discussions, emphasising the integration of sustainability in engineering education. Given the escalation from urgency in 2004 to a critical state in 2024, there is a pressing need to transform

the paradigm of engineering education to address the current alarming challenges more effectively. In the last three decades, there has been a growing push to incorporate concepts of sustainability and sustainable development into engineering education (Segalàs Coral, Drijvers, & Tijseen, 2018). Education for Sustainable Development (ESD) is perceived as an educational approach that promotes changes in knowledge, skills, values, and attitudes, aiming to cultivate a society that is both sustainable and equitable for everyone (UNESCO, 2017, p. 7). UNESCO declares that *Education for sustainable development (ESD) gives learners of all ages the knowledge, skills, values and agency to address interconnected global challenges including climate change, loss of biodiversity, unsustainable use of resources, and inequality* (UNESCO 2022). Several papers discuss the integration of sustainable development goals in engineering education, different methodologies are suggested, (Ramirez-Mendoza et al, 2020, Llopis-Albert et al., 2022) according to (Llopis-Albert et al., 2022) suggested some measures and indicators that can help to integrate SDGs in mechanical engineering syllabus. According to (Huimin Chen et al., 2022) governance constitutes a pillar in integration of SD in Engineering education. Active learning approaches are essential for Engineering Education for Sustainable Development (EESD) (Quelhas et al., 2019) we can use problem-based, project-based learning, challenge-based learning, etc. The PBL models can be considered as learning models in engineering syllabus (Pérez-Sánchez et al., 2020). The perceptions are different with a main goal, which is how to improve engineering education in a world continuously challenging. The limit in these works is a concrete approach that can be generalised to all disciplines.

## **THE EVOLUTION OF THE CDIO STANDARDS TOWARD SUSTAINABILITY**

The Conceive-Design-Implement-Operate (CDIO) framework emerges as a pioneering educational approach, emphasising a practical, project-based learning paradigm that mirrors the complexities of real-world engineering. Within this context, the Optional Standard 1: Sustainable Development in the CDIO framework stands out. (Malmqvist et al., 2020). It advocates for the integration of sustainability—a triad of environmental, social, and economic considerations—into the engineering curriculum. This standard recognizes the imperative to imbue future engineers with the ethos of sustainability, ensuring that they are problem solvers and guardians of our planet's future.

As the modifications in CDIO standards 2.1 (Bennedsen et al., 2016) have been relatively minor and have not changed the scope or the main contents of the standards. The version 2.1 does not present major changes from 2.0, we are here comparing 2.0 Version to version 3.0. The shift from CDIO Standards version 2.0 (Crowley et al., 2014) to 3.0 (Malmqvist et al., 2022) reflects a significant evolution in engineering education, aligning it more closely with contemporary global challenges, especially in sustainable development. This transition is a strategic enhancement, integrating a deeper focus on sustainability and reflecting the changing landscape of engineering practice and education.

### **Enhancements in Version 3.0**

Version 3.0 of the CDIO Standards (Malmqvist et al., 2022) marks a deliberate move towards embedding sustainability into the heart of engineering education.

#### *Integration of Sustainability and SDGs:*

A critical update in version 3.0 is the explicit inclusion of sustainability. This integration signifies a shift in engineering education towards a broader global and societal perspective, recognizing the crucial role of engineers in addressing global challenges.

The updates affected the context (standard 1), learning outcomes (standard 2), Integrated Curriculum (standard 4), Engineering learning workplaces (standard 7), Enhancement of faculty competence (standard 9) and finally Learning assessment (standard 11). The new version places a greater emphasis on considering environmental, social, and economic sustainability as an integral part throughout the lifecycle, developing skills related for sustainable development (Malmqvist et al., 2022). For Integrated Learning Experiences (Standard 7), the updated standards encourage pedagogical approaches that enhance the learning of disciplinary knowledge, acknowledging the interconnected nature of modern engineering problems. This approach is vital for sustainability education, as it involves complex interactions between various fields. Regarding enhancement of faculty competence (Standards 9) version 3.0 underscores the need for faculty development in contemporary teaching methodologies and sustainability education. This ensures that educators are equipped to deliver a curriculum that is both modern and relevant to current global challenges.

### **Comparison with Version 2.0**

While version 2.0 (Crawley et al., 2014) laid a strong foundation by emphasising integrated curriculum design and industry engagement, version 3.0 builds upon this by infusing sustainability throughout the educational process. The elements in version 3.0 (Malmqvist et al., 2020), such as the integration of sustainability and emphasis on personal and professional skills, are not entirely absent in version 2.0 but are significantly expanded and given more prominence in the latest version. This evolution reflects a response to the increasing importance of sustainability in engineering and the need for a curriculum that prepares students to meet these challenges.

## **METHODOLOGY**

The primary aim of this paper is to propose a comprehensive framework that seamlessly integrates the principles of Optional Standard 1: Sustainable Development into the 12 fundamental CDIO standards. The paper "Mapping the CDIO Syllabus to the UNESCO Key Competencies for Sustainability" (Rosén et al., 2019), focuses on evaluating the relevance of the CDIO Syllabus in promoting engineering education for sustainable development. The evaluation employs a framework of key competencies for sustainability defined by UNESCO. This is conducted in two main steps: firstly, identifying topics, terms, and concepts in the CDIO Syllabus corresponding to the UNESCO key competencies, and secondly, a qualitative discussion highlighting areas of strong mapping and suggesting improvements to the Syllabus. The paper concludes that the CDIO Syllabus aligns well with the UNESCO framework but identifies several opportunities for further enhancement in relation to the key competencies. This study also acknowledges the UNESCO key competencies as essential instruments in

guiding the evolution of the CDIO Syllabus, thereby paving the way for the development of version 3.0 of both the standards and Syllabus 3.0. Following this, we explore further the alignment between the CDIO Syllabus and the 17 UN SDGs, highlighting how certain CDIO elements can be achieved by incorporating courses or learning themes related on some selected SDGs:

*CDIO Syllabus 1.4 (Knowledge of Social Science and Humanities) & SDG 4 (Quality Education)*

In a course on engineering ethics, include case studies focusing on sustainable development and social responsibility. Students can learn about the ethical implications of engineering decisions on society and the environment, thus addressing both the knowledge of social sciences and humanities and promoting quality education through awareness of sustainable development.

*CDIO Syllabus 2.2.3 (Experimental Inquiry) & SDG 6 (Clean Water and Sanitation)*

In a laboratory module on environmental engineering, introduce experiments related to water purification technologies and wastewater management. This directly ties experimental inquiry with the goal of ensuring availability and sustainable management of water and sanitation for all.

*CDIO Syllabus 2.3.3 (Prioritization and Focus) & SDG 13 (Climate Action)*

In courses on project management and engineering design, include projects that focus on designing solutions for climate change mitigation or adaptation. This could involve prioritising and focusing on developing renewable energy sources, energy-efficient buildings, or climate-resilient infrastructure.

*CDIO Syllabus 2.5.5 (Equity, Diversity, and Inclusiveness) & SDG 5 (Gender Equality)*

In leadership and team management courses, emphasise the importance of gender equality, diversity, and inclusion in engineering teams. Addressing these issues can promote a more equitable and inclusive environment in the engineering profession, aligning with SDG 5.

*CDIO Syllabus 3.1.3 (Stakeholder Engagement) & SDG 11 (Sustainable Cities and Communities)*

In urban planning and civil engineering courses, incorporate projects that require engagement with community stakeholders to design sustainable urban spaces, thus teaching students the importance of considering diverse perspectives in creating sustainable cities and communities.

*CDIO Syllabus 4.1.2 (The Impact of Engineering on Society and the Environment) & SDG 15 (Life on Land)*

In environmental engineering courses, focus on the impact of engineering projects on terrestrial ecosystems and biodiversity. This could include studying the effects of construction on wildlife habitats and exploring engineering solutions to minimise negative impacts.



*CDIO Syllabus 4.6.5 (Disposal, End-of-Life, and Circularity) & SDG 12 (Responsible Consumption and Production)*

In manufacturing and materials science courses, emphasise the principles of circular economy and sustainable material management, teaching students how to design products with sustainable life cycles, from production to disposal.

*CDIO Syllabus 5.2 (Engineering Entrepreneurship) & SDG 8 (Decent Work and Economic Growth)*

Encourage entrepreneurial thinking in engineering students by focusing on start-ups and innovations that contribute to sustainable economic growth and provide decent work opportunities. This could involve workshops on sustainable business models and green technologies. By brainstorming on relevant examples to introduce into the engineering curriculum, educators can create a more comprehensive and sustainability-focused educational experience that prepares students to address global challenges in their professional careers.

***CDIO Standards 3.0 and UN SDGs: Synergizing for Impactful Engineering Education***

We focus on examining CDIO standards, offering an interpretation and deployment strategy that aligns with institutions prioritising sustainability and environmental protection in their engineering curricula. This nuanced interpretation seeks to guide institutions in effectively adapting CDIO standards to meet the evolving demands of environmental stewardship within the engineering discipline.

*CDIO Standard 1 "The Context,"* positions sustainability at the center of engineering education, emphasizing its integration as a core principle, not just an addition. This standard guides the conception, design, implementation, and operation of projects within a sustainability framework, creating a mindset among graduates that is technically adept, ethically grounded, and globally aware.

*CDIO Standard 2, "Learning Outcomes,"* requires specific and detailed outcomes for personal and interpersonal skills, product, process, system, and service building skills, along with disciplinary knowledge. These outcomes, aligned with program goals, are validated by key stakeholders. The CDIO Syllabus codifies these outcomes, outlining the knowledge, skills, and attitudes students should possess upon completing their engineering programs. Programs are encouraged to tailor the CDIO Syllabus to their specific needs and define the proficiency levels expected for each learning outcome.

Here is our concept for constructing an engineering education program centred around the SDGs: In the syllabus of each teaching unit, one or more learning outcomes should be defined in connection with the SDGs. This can be either a direct relationship with specific SDGs or targeting the key competencies for sustainable development as defined by the UN. This approach ensures that every aspect of the engineering curriculum is directly contributing to global sustainability goals. This strategy should be infused into all four areas of the CDIO Syllabus. There is always a possibility to align the CDIO Syllabus with the 17 SDGs and the 8 key competencies for sustainable development. For instance, in a fluid mechanics course, while the learning objectives might traditionally focus on establishing and utilising the Bernoulli equation, additional learning outcomes can be integrated to demonstrate how this equation can aid in designing systems that minimise fluid loss, such as in water systems. Alongside this,

in thermodynamics, strategies to reduce or harness evaporation can be explored. Building on this approach, in a course on materials science, learning outcomes could include understanding the selection of sustainable materials and their life cycle impacts, aligning with SDG 12 on responsible consumption and production. Similarly, in a course on electrical engineering, students could explore the design of energy-efficient systems, contributing to SDG 7, which focuses on affordable and clean energy. In a civil engineering module, learning outcomes might involve planning sustainable urban infrastructures, thereby addressing SDG 11 on sustainable cities and communities. This holistic integration of the SDGs into the engineering curriculum broadens the scope of learning outcomes while aligning engineering education with global sustainability objectives.

This methodology does not require a complete overhaul or redesign of a course's learning objectives. It involves a thoughtful examination by the teaching team responsible for the module, exploring possible connections with sustainable development goals. Initially, this entails identifying learning achievements that can be incrementally added to the existing ones. Once this step is accomplished, the teaching team, utilising student feedback, will have the necessary insights to consider a total redesign of the teaching unit while consequently reevaluating pedagogical alignment. Furthermore, the process includes validation of the program by stakeholders – such as industry partners, alumni, and community representatives – ensuring that the modified curriculum aligns with academic standards and society's fast-changing requirements. Integrating the challenges faced by our planet brings relevance to the course and actively engages students who are part of a generation seeking meaningful contributions and deeply concerned about climate change, inequalities, and the scarcity of vital resources.

### *Standard 3: Integrated Curriculum*

Designing an engineering program under CDIO Standard 3, focused on SDGs, involves a strategic, multidisciplinary curriculum aligned with sustainability goals. Key steps include curriculum mapping for sustainability competencies, balanced SDG coverage, interdisciplinary faculty training, and practical projects addressing real-world sustainability issues. Continuous program evaluation with feedback from students, faculty, and industry, plus involvement of external stakeholders in development and assessment, ensures the program stays relevant and responsive to evolving sustainability challenges.

### *Incorporating Standard 5*

Integrating Design-Implement Experiences in an SDG-focused engineering program requires a methodical approach, progressively aligning with SDGs and escalating from simple to complex projects. This aligns with Standard 1, ensuring a comprehensive grasp of product and system development from conception to operation. Emphasizing sustainability and ethics, these experiences connect with real-world challenges through industry and NGO partnerships. Co-curricular activities, such as research and internships focused on SDGs, further enrich student understanding and engagement with global issues.

### *Standard 9: Enhancement of Faculty competence*

To align faculty competence with SDG-focused engineering programs under Standard 9, a multi-dimensional strategy is needed. Faculty development should include sustainable development skills, professional development opportunities in sustainable engineering, and industry collaborations. Practical industry experience in sustainability roles is crucial for faculty.

Hiring and promotion criteria should prioritize sustainable development expertise, and a support system with training, mentorship, and resources is essential. This comprehensive approach enhances faculty's capability to effectively teach and engage in SDG-related research and education.

### *Implementing Standard 11: Learning Assessment*

The assessment should measure understanding and application of sustainability concepts, in accordance with Standards 2, 3, and 7. Techniques like written, online, and oral exams, observations, rating scales, journals, portfolios, and peer/self-assessments ensure a comprehensive evaluation of students' capabilities in sustainability and engineering.

## **DISCUSSION**

Integrating sustainability and the UN Sustainable Development Goals into engineering curricula brings several challenges. First, teachers' challenges can be resumed in four blocks: shifting paradigms around sustainability, the rigidity of the existing curricular structure; requirement of new teaching methods and lack of resources to teach sustainability in faculty (Zhang et al, 2012). Therefore, training and adaptation are imperative; educators must be sufficiently equipped and confident in incorporating these new concepts into their teaching methodologies, resource allocation also becomes a significant factor, necessitating additional investment for the development of new materials, faculty training, and course restructuring. Furthermore, the process of assessment and evaluation demands innovation, requiring new metrics and methods to effectively measure student learning within this sustainability-focused context. Finally, aligning the interests and expectations of diverse stakeholders, including industry partners, academic institutions, and students, presents a complex challenge. This alignment is crucial to ensure the relevance and effectiveness of the modified curriculum and its alignment with broader educational and societal goals. Several studies have found that while students recognize the importance of sustainable development (SD), many are not familiar with its concepts . This leads to a disconnect between valuing sustainability and implementing it in practice (Dagiliūtė et al., 2018, Perrault et al., 2017, Chaplin et al., 2014). However, they are more inclined to engage in sustainable behaviours, such as eco-friendly purchasing, recycling, and conserving energy or water, when they reflect on their consumer responsibilities (Chaplin et al., 2014). To enable students to successfully integrate the process, it's crucial to blend essential knowledge, skills, and attitudes. This combination leads to the creation of innovative, sustainable solutions aligned with their chosen UN SDGs. To enhance students' capacity to effectively amalgamate these skills, it's important to initially offer ample practical application opportunities for developing these fundamental skills. By offering adequate support and guidance, we can assist students in building robust knowledge frameworks, "that are accurately and meaningfully organized and help students to better able to retrieve and apply their knowledge effectively." (Ambrose, Bridges, Lovett, & Norman, 2010, pp. 4-5).

Sustainable development, with its multi- and transdisciplinary nature, presents a unique challenge in the context of higher education's traditional discipline-based approach to knowledge and research. Balancing these two aspects poses a significant hurdle for universities in incorporating sustainable development learning into their curricula (Van Dam-Mieras, 2006; Mulder et al., 2006).

## CONCLUSION

The presented work offers an incremental framework for integrating sustainable development principles, particularly those outlined in Optional Standard 1: Sustainable Development, into the 12 core CDIO (Conceive-Design-Implement-Operate) standards. This initiative is designed to address the urgency of contemporary global challenges, as summarised in the United Nations Sustainable Development Goals (UN SDGs). Recognising the significant impact of the engineering profession on life on Earth, our proposition seeks to reorient engineering education to equip future engineers with the necessary tools to confront and mitigate the pressing threats facing our societies, the planet, and its inhabitants. By aligning engineering curricula with the UN SDGs, this approach focuses on the critical role of engineers in responding to these imminent challenges with precision and efficacy.

The framework introduced in the paper does not call for a complete revamp of existing curricula. Instead, it suggests a meticulous examination and gradual incorporation of sustainable development objectives. This process requires the integration of relevant learning outcomes within the current curriculum, with a focus on ensuring that every element of engineering education is directly contributing to global sustainability objectives. This approach is meant to be comprehensive, permeating all facets of the CDIO Syllabus for thorough integration of the SDGs.

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# ARTIFICIAL INTELLIGENCE IN ELECTROMECHANICAL ENGINEERING: THE ESPRIT MODEL

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## ABSTRACT

In response to the surge of artificial intelligence (AI) in the last decade, which now spans across electromechanical sectors like automation, electricity, and maintenance, the ESPRIT approach is introduced. It emphasizes the need for engineers to diversify their skill sets to adapt to the evolving landscape. This educational paradigm integrates an AI module into the electromechanical engineering curriculum, congruent with CDIO standards, to cultivate a broad spectrum of competencies in AI. The curriculum is meticulously crafted to progress from foundational knowledge to advanced application and assessment, employing active learning strategies to enhance students' technical, problem-solving, and professional skills, ultimately encouraging a well-rounded mastery of AI in engineering. This paper describes the ESPRIT approach, a pedagogical paradigm tailored for equipping electromechanical engineers with the necessary AI competencies. The integration of a dedicated AI module within ESPRIT's electromechanical engineering curriculum aligns with the CDIO standards, marking a significant stride in engineering education. Our pedagogical contribution is threefold, encapsulating the design, execution, and evaluation of the AI module over a span of three years. The curriculum employs active learning strategies (standard 8) to immerse students in AI problem-solving, fostering an environment of practical engagement. The curriculum unfolds in a structured manner (standard 3), starting with the AI discovery phase in the third year, where students acquaint themselves with Python, AI libraries, and foundational AI concepts, including elementary classification and regression algorithms. The second phase, in the fourth year, pivots on the application and reinforcement of the knowledge acquired, with a focus on the lifecycle of an AI project. Students culminate this stage by undertaking a mini project adhering to AI project conventions. The final phase, in the fifth year, emphasizes practical application and mastery, culminating in an NVIDIA DLI workshop where students have the opportunity to earn a certificate in AI for predictive maintenance. In conclusion, the paper presents a critical analysis of this pedagogical approach, highlighting its pragmatic applications and the well-paced learning trajectory that aligns with student capability. Nonetheless, it underscores the imperative of achieving a symmetrical balance between the theoretical and practical aspects of AI to fully harness its potential in electromechanical engineering.

## KEYWORDS

Artificial Intelligence, Electromechanical engineering, engineering education, Predictive maintenance, Standards: 1, 2, 3, 5, 6, 8, 11

## INTRODUCTION

Integration of artificial intelligence (AI) into engineers' education across various disciplines, including mechanical, electrical, civil, electromechanical, and biological engineering, is gaining increasing significance due to the numerous advantages it brings to the industrial landscape (Chen, Chen, & Lin, 2020; Lee, Bagheri, & Kao, 2015; Novatchkov & Baca, 2013). It enhances students' skills and prepare them to cope better with the world challenges (Chen et al., 2020).

In this context, our focus centers on the integration of AI into the training of electromechanical engineers. The rationale behind this imperative integration is multifold:

First and foremost, the rapid progression of AI and automation is reshaping the electromechanical industries (Lee et al., 2015), compelling engineers to acquaint themselves with these technologies to remain abreast of the latest advancements and sustain competitiveness in the job market.

AI proves instrumental in optimizing manufacturing processes, predictive maintenance, and operations management within electromechanical industries. It plays a pivotal role in proactively identifying potential failures and breakdowns, contributing to enhanced efficiency and reduced downtime. Furthermore, AI training equips engineers with the skills to apply advanced diagnostic techniques, leading to minimized downtime and maintenance costs, thereby meeting the stringent demands of the electromechanical industry (Novatchkov & Baca, 2013).

The facilitation of communication between humans and machines is another significant advantage of AI. Engineers trained in AI can design interactive and intelligent systems, resulting in the creation of more user-friendly and efficient man-machine interfaces. AI opens new avenues for innovation in the design of electromechanical products and solutions. Engineers versed in both electromechanics, and AI can introduce inventive ideas to address complex challenges and design more intelligent systems. Hence, there is a growing demand for electromechanical engineers with AI expertise to assist these companies in maintaining competitiveness on a global scale (Humble & Mozelius, 2019).

Finally, the integration of AI into the training of electromechanical engineers imparts versatility. This ensures that engineers are adept at comprehending and contributing to projects involving mechanical, electrical, and IT components (Crawley, Malmqvist, Ostlund, Brodeur, & Edstrom, 2007).

In conclusion, integrating AI into the education of electromechanical engineers is imperative for preparing the upcoming generation to confront present and future technological challenges while maximizing the benefits of these advancements within the industrial sector. Electromechanics, despite being a field with a rich history of exploration, continues to undergo constant technological advancements (Grüner et al., 2020).

Several papers discussed the integration of AI in Engineering according to CDIO framework (Cao & Sun, 2020; Edström & Kolmos, 2014; Tsai, Wang, Peng, Huang & Tsai, 2018). While traditional training for electromechanical engineers covers fundamental aspects of electricity and mechanics, the evolving demands of the contemporary industry necessitate a broader skill set.



In recognition of this need for a more comprehensive skill set, ESPRIT Private school of Engineering and Technology has been proactive in updating its electromechanical curriculum since 2018. The curriculum overhaul specifically addresses the imperative of integrating artificial intelligence (AI) into the skill repertoire of electromechanical engineers.

This novel module is distinctive in its approach, considering prerequisites in essential areas such as basic mathematics, numerical analysis, probability, and statistics, as well as algorithmics and computer science. Moreover, the module is strategically structured over a three-year duration, aligning with the CDIO (Conceive, Design, Implement, Operate) reference framework.

The CDIO framework, an educational approach emphasizing Conceive-Design-Implement-Operate, serves as the guiding principle for the development of the Artificial Intelligence module at ESPRIT. This approach entails a strategic three-year plan that aligns with the CDIO framework, facilitating a gradual and systematic integration of AI-related knowledge and skills throughout the curriculum.

This strategic update aims to equip electromechanical engineers not only with traditional mechanical and electrical skills but also with the cutting-edge proficiency in artificial intelligence. By incorporating AI into the curriculum, ESPRIT aims to produce operational electromechanical engineers who can effectively address the evolving needs of industry and contribute to technological innovation in the field.

The AI module spans three years, with each year's students engaging in a module encompassing 21 hours of instruction. The schedule unfolds as follows:

During the third year of the electromechanical engineer training program, the initial module titled "Introduction of Artificial Intelligence" is scheduled. This module aims to empower students to design and explore the fundamental concepts of AI.

In the fourth year of the electromechanical engineer training program, the subsequent module, labelled "Machine Learning 1", is incorporated. The primary objective of this module is to solidify AI knowledge and introduce new insights into machine learning. Throughout the course, students apply this knowledge to address challenges within the electromechanical domain.

Advancing to the fifth year of electromechanical engineer training, the third module, named "Machine Learning 2", is outlined. In this module, students deepen their understanding of AI and leverage this expertise to tackle real-world problems. Successful completion of this module results in the attainment of an AI certificate.

The paper will be organized as follows, we will explain why we have planned the AI over three years, then the methodology used according to the CDIO referential, then we will detail each module by explaining the objectives, pedagogy adopted, evaluation, etc.

## METHODOLOGY AND JUSTIFICATION

Artificial intelligence is the overarching system. Machine learning is a subset of AI. Deep learning is a subfield of machine learning, and neural networks make up the backbone of deep learning algorithms. It's the number of node layers, or depth, of neural networks that distinguishes a single neural network from a deep learning algorithm, which must have more than three.

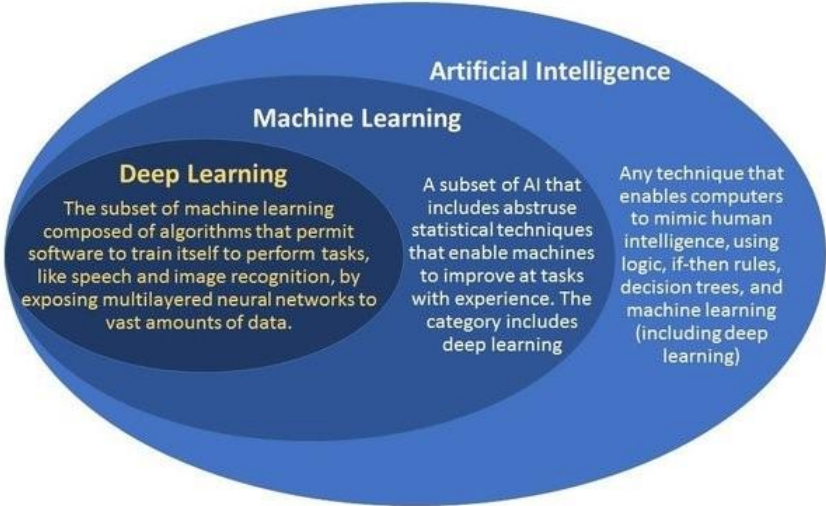


Figure 1. 3 faces of artificial intelligence: IA VS ML VS DL

The depicted Figure 1 illustrates these incorporations. Drawing inspiration from this representation, we conceived a strategy to integrate three artificial intelligence modules into the electromechanical curriculum, commencing from the third year onward. The primary objective of the initial module is to lay the groundwork for the AI domain and delve into the machine learning subdomain. In the subsequent module, the emphasis shifts to the machine learning subdomain, specifically on its creation and implementation. Upon completion of this module, students are expected to execute a mini machine learning project, showcasing a well-defined pipeline. The third module homes in on the deep learning subdomain of machine learning, where all acquired knowledge is put into practice. A workshop, resulting in a certificate, serves as the culmination of this module.

For a comprehensive overview of the final planning of these three modules and their alignment with the CDIO framework, please refer to the detailed Figure 2 provided below.

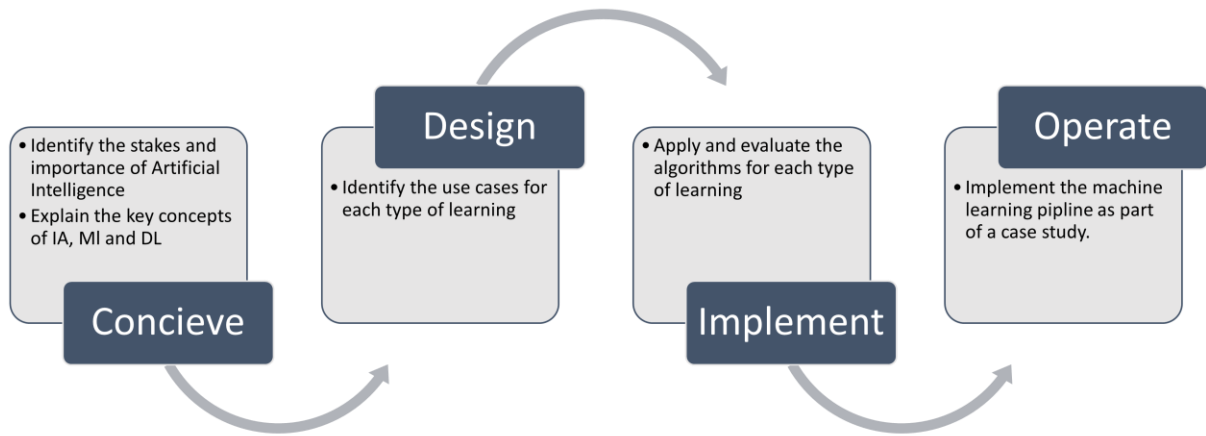


Figure 2. Learning outcomes and CDIO framework

## CDIO APPROACH IN INCORPORATION OF ARTIFICIAL INTELLIGENCE (AI) FOR ELECTROMECHANICAL ENGINEERS

The integration of AI unfolds in three distinct phases, each spanning a year and implemented through the design of a dedicated module.

### *Introduction of artificial intelligence (AI)*

In the third year of the electromechanical engineering course, the inaugural module focusing on artificial intelligence is scheduled. This module spans a duration of 7 weeks, carrying a credit value of 2 ECT. It signifies the initiation of the AI design phase for electromechanical engineering students. Throughout this module, students delve into the fundamental concepts of AI through a combination of theoretical lectures. Their comprehension of these concepts is evaluated through a multiple-choice questionnaire (MCQ). Subsequently, students apply their acquired knowledge by leveraging digital tools, notably utilizing the Python programming language and AI libraries to implement practical aspects of AI (see Figure 4).



Figure 3. AI libraries and tools

Next, the student focuses on solving supervised and unsupervised learning problems using ready-to-use databases. This phase is approached through practical work guided by theoretical notions. Assessment for this module consists of a continuous assessment grade, representing 40% of the final grade, and an examination comprising theoretical and practical MCQs, awarding 60% of the total grade. We begin by providing the Table 1, correlating the learning objectives with the CDIO reference framework.

Table 1. Learning outcomes and CDIO framework

|                                                               |            |
|---------------------------------------------------------------|------------|
| Learning outcomes                                             | CDIO       |
| Identify the stakes and importance of Artificial Intelligence | Conceive.  |
| Explain the key concepts of AI , ML and DL                    | Conceive.  |
| Distinguish between the different types of machine learning   | Conceive.  |
| Identify the use cases for each type of learning              | Design.    |
| Apply the algorithms of each type of learning                 | Implement. |
| Evaluate the performance of different learning algorithms     | Implement. |

A summary of this first module is given in the Table 2.

Table 2. Introduction of IA roadmap

|        | Course content                                         | Duration | Report    | Assessment     |
|--------|--------------------------------------------------------|----------|-----------|----------------|
| Week 1 | Introduction to Artificial Intelligence                | 3 hours  | No report | MCQ            |
| Week 2 | Background on the Python language                      | 3 hours  | Notebook  | No assessment  |
| Week 3 | AI libraries and tools/ Pandas, Seborne                | 3 hours  | Notebook  | MCQ            |
| Week 4 | Manipulate supervised learning methods: Classification | 3 hours  | Notebook  | No assessment  |
| Week 5 | Manipulate supervised learning methods: Classification | 3 hours  | Notebook  | practical work |
| Week 6 | Manipulate supervised learning methods: Regression     | 3 hours  | Notebook  | No assessment  |
| Week 7 | Manipulate supervised learning methods: Regression     | 3 hours  | Notebook  | practical work |

### **Machine learning 1**

In the fourth year of the electromechanical engineering course, the second module entitled "Machine Learning 1" is scheduled. This module extends over a period of 7 weeks, with a value of 2 ECT credits. It represents the creation and realization phase. The module begins with a reminder of artificial intelligence (AI) and an update of information, presented through lectures and practical work. This part is validated by questions and MCQs. The main objective of this module is to master the pipeline of a machine learning project, from data exploration to data preparation and data modelling. The examples covered come from the field of electromechanics. To validate the module, a mini project is launched during the second-class session.

This mini project involves solving a machine learning problem from A to Z. Students are divided into groups of 6 for this project, with the choice of groups left to the students. Tasks are divided between the groups, and students receive coaching at each class session. The module is validated through this project, and students must submit a final report organized according to a Data Science work methodology (project pipeline), well-commented source code (Notebooks), and an oral presentation. The Figure 4 shows the pipeline used by the students to create the mini project.

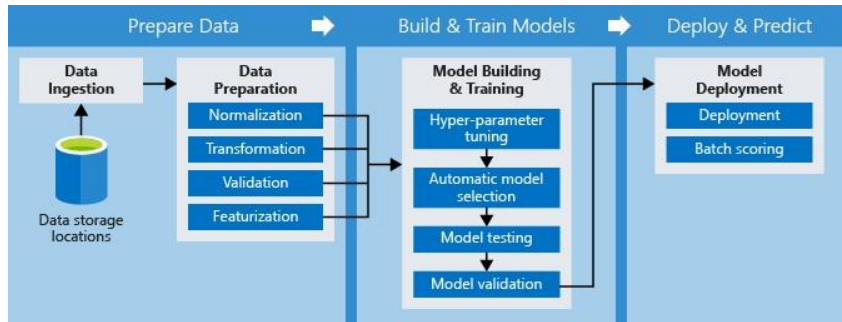


Figure 4. Pipelines for mini project

We begin by providing the Table 3, correlating the learning objectives with the CDIO reference framework.

Table 3. Learning outcomes and CDIO framework

| Learning outcomes                                                                  | CDIO                  |
|------------------------------------------------------------------------------------|-----------------------|
| Identify the stakes and importance of machine learning                             | Conceive.             |
| Differentiate between the main phases of a machine learning project                | Conceive and Design.  |
| Distinguish and identify the use cases for the different types of machine learning | Conceive.             |
| Apply the algorithms of each type of learning                                      | Design and Implement. |
| Interpret the performance of different learning algorithms                         | Implement.            |
| Interpret the models resulting from machine learning                               | Implement.            |
| Suggest improvements to the various learning models                                | Implement             |

The table 4 below summarizes the details of this module.

Table 4. Machine Learning 1 roadmap

|        | Course content                      | Duration | Report              | Assessment        |
|--------|-------------------------------------|----------|---------------------|-------------------|
| Week 1 | Introduction to machine learning    | 3 hours  | Presentation        | oral presentation |
| Week 2 | project pipeline and project launch | 3 hours  | No report           | No assessment     |
| Week 3 | Ensemble learning: Bagging          | 3 hours  | Notebook            | practical work    |
| Week 4 | Ensemble learning: Bagging          | 3 hours  | Notebook            | practical work    |
| Week 5 | Unsupervised learning               | 3 hours  | Notebook            | practical work    |
| Week 6 | Neural network: Regression          | 3 hours  | Notebook            | practical work    |
| Week 7 | Project validation                  | 3 hours  | Notebook and report | oral presentation |

## Machine Learning 2

In the fifth year, the final stage of the electromechanical engineering education, the "Machine Learning 2" module is scheduled to last 7 weeks. The first five weeks will be dedicated to lectures consisting of a combination of theoretical sessions, tutorials and practical work. During this period, the students will consolidate their knowledge of classical machine learning, while discovering a subfield, deep learning. The pedagogy favors an active approach where the student is at the center of the learning process. The last two sessions will be combined in a single day in the form of a workshop. The aim of this workshop is to explore the use of AI in a real-life context, specifically in the field of electromechanics. Entitled "Applications of AI for Predictive Maintenance," the workshop is run by the NVIDIA DLI INSTITUTE NVIDIA (n.d.).

The Prerequisites of this workshop are:

- Experience with Python.
- Basic understanding of data processing and deep learning.

The learning Objectives of this workshop are:

- Use AI-based predictive maintenance to prevent failures and unplanned downtimes.
- Identify key challenges around detecting anomalies that can lead to costly breakdowns.
- Use time-series data to predict outcomes with XGBoost-based machine learning classification models.
- Use an LSTM-based model to predict equipment failure.
- Use anomaly detection with time-series autoencoders to predict failures when limited failure-example data is available.

The student validates the Machine Learning 2 module by obtaining a certificate and taking an MCQ exam covering both theoretical and practical aspects. The Table 5 summarizes the details of this module.

Table 5. Machine Learning 2 roadmap

|          | Course content                                                     | Duration | Report       | Assessment             |
|----------|--------------------------------------------------------------------|----------|--------------|------------------------|
| Week 1   | Overview of Machine learning and introduction to deep learning     | 3 hours  | Presentation | oral presentation      |
| Week 2   | Classification and regression using an artificial neural network   | 3 hours  | Notebook     | practical work         |
| Week 3   | Convolutional Neural Network                                       | 3 hours  | Notebook     | practical work         |
| Week 4   | Convolutional Neural Network                                       | 3 hours  | Notebook     | practical work         |
| Week 5   | Recurrent Neural Network and LSTM                                  | 3 hours  | Notebook     | practical work         |
| Week 6,7 | NVIDIA DLI Workshop: Applications of AI for Predictive Maintenance | 6 hours  | Certificate  | MCQ and practical work |

## **ALIGNMENT WITH CDIO STANDARDS**

In the electromechanical engineering curriculum at ESPRIT Private School of Engineering, the incorporation of Artificial Intelligence (AI) is aligned with the CDIO (Conceive, Design, Implement, Operate) standards (Malmqvist et al., 2019), ensuring a comprehensive and application oriented educational experience.

The Learning Outcomes (Standard 2) are specific and designed to help students acquire skills through all AI courses integrated in their curriculum.

The curriculum's alignment with Standard 3, Integrated Curriculum, begins with the third year's "Introduction of Artificial Intelligence" module, where foundational AI concepts are introduced alongside Python AI libraries. It is exemplified in the third year's "Introduction of Artificial Intelligence" module, where foundational AI concepts are seamlessly blended with practical Python AI libraries. This approach lays a solid groundwork for advanced learning, adhering to the CDIO initiative of integrating theoretical knowledge with practical skills.

Transitioning to Standard 5, Design-Build Experiences, the curriculum peaks in the fifth year with "Machine Learning 2." Here, students engage in hands-on experiences, notably through the NVIDIA DLI workshop on AI for predictive maintenance, which bridges the gap between classroom learning and real-world applications. This standard emphasizes the importance of experiential learning, enabling students to conceive and design solutions to actual engineering challenges.

Active Learning, as per Standard 8, is a cornerstone of the fourth year's "Machine Learning 1" module. This phase of the curriculum involves an interactive and engaging learning process, highlighted by a mini project. This project allows students to implement their learning and fosters a deep understanding of AI's practical applications, crucial for future engineers.

Lastly, Standard 11, Learning Assessment, is integral to the AI module. Continuous and varied assessments, including project -based evaluations, ensure that students acquire theoretical knowledge and also develop the practical skills necessary in the electromechanical industry. This standard guarantees that the learning outcomes are in line with both academic and industry standards, thereby producing well-equipped engineers.

## **CONCLUSION**

This paper has explored the integration of Artificial Intelligence (AI) into the electromechanical engineering curriculum at ESPRIT Private School of Engineering, highlighting a forward-thinking approach in engineering education. In an era where AI is increasingly becoming a cornerstone in various sectors, notably in electromechanical fields like automation, electricity, and maintenance, ESPRIT's initiative stands as a testament to the necessity and effectiveness of incorporating advanced technologies into educational frameworks. The ESPRIT approach is not limited to the inclusion of AI concepts into the curriculum; it represents a paradigm shift in engineering education. By aligning with the CDIO standards, particularly focusing on Standards 2, 3, 5, 8, and 11, this curriculum ensures a comprehensive educational process. From the initial stages of acquiring foundational knowledge to the advanced stages of application and mastery, the curriculum is designed to build both technical and professional competencies. The use of active learning strategies, as emphasized in Standard 8, and a

structured progression in learning, as per Standard 3, are integral to this process. Moreover, the ESPRIT model's pedagogical contribution extends beyond traditional educational models. It represents an approach to designing, executing, and evaluating the AI module. This threefold methodology, spread over three years, allows students to discover AI concepts, reinforce and apply their knowledge, and achieve practical application and mastery. This approach ensures that students are well-equipped in AI theories and become proficient in applying these concepts in real-world scenarios, a crucial skill in the ever-evolving field of electromechanical engineering. In conclusion, the ESPRIT Private School of Engineering's approach in integrating AI into its electromechanical engineering curriculum can serve as an example for other institutions. It demonstrates the importance of evolving curricula to include emerging technologies and methodologies, preparing students to be adept engineers who can contribute to the complex technological landscapes of the future.

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# THE DEVELOPMENT OF A SELF-PACED ONLINE COURSE ON SUSTAINABLE DEVELOPMENT FOR ENGINEERS

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## **ABSTRACT**

Building knowledge of sustainable development in engineering undergraduates equips them to develop future solutions to a variety of societal, environmental and economic challenges. A credit-bearing course has been developed over the last two years at the University of Liverpool to introduce Sustainable Development to first-year Engineering students. Respecting the diverse background and prior experience of this cohort, the course aimed to raise appreciation of global challenges and the role of professional engineers in contributing to their solutions, whilst giving students a knowledge baseline to provide context for further learning in sustainable engineering. It built on an existing self-paced online resource co-created with students, adding newly developed material and including sustainable development case studies specific to engineering. It was structured around the 17 UN Sustainable Development Goals in the context of the 5 P's: People, Planet, Prosperity, Peace and Partnerships. Case studies were aligned to one of the 5 P's with a commentary highlighting how and why engineers were involved in the activity. Assessment was an open book, online MCQ to check engagement and understanding, covering each of the 5 P's. After the first year of implementation, student feedback and satisfaction levels were gathered in an anonymous survey, with engagement measured by rates of completion in the MCQ assessment, and by online page view statistics. Following this, operational adjustments and course updates were made to address some of the major student feedback. This included greater explanation of the engineering skills and solutions that were employed in the case studies, and attempting to address what some students felt were subjective questions. Following updates to the self-paced course, it was deployed and evaluated during a second year. Future refinement will be informed by evaluating how this activity supported students during the rest of their studies, by building baseline knowledge of and appreciation for sustainable engineering across the cohort.

## **KEYWORDS**

Sustainable Development, Student Co-creation, Student Engagement, Self-paced Learning, Standard: 1

## INTRODUCTION

There are many drivers for engineering students to study sustainable development. A chief reason is to prepare engineering graduates for the challenges and threats to people around the world and to Earth's natural environment. Frameworks exist to categorise these challenges, for example the UN Sustainable Development Goals (SDGs) (United Nations, 2015).

Engineers in particular are and will be vital for developing sustainable solutions to the full range of these global challenges. In the QAA Subject Benchmark Statement for Engineering (QAA, 2023), sustainability and sustainable development are given priority in that document's overall definition of engineering and the importance of how engineers can help to achieve the UN SDGs is included.

Therefore, engineering graduates must contribute to the challenges typical to engineering, such as decarbonisation, and also those perhaps seen as less typical, such as eliminating poverty. The broad range of sustainable development and sustainable engineering solutions should be introduced early into an engineering degree programme to prepare students for this. Exposure to sustainable development solutions will additionally provide forward motivation for students to see how their studies can result in real-world improvements.

To develop sustainable solutions, engineers will develop skills in resilience, adaptability and problem-solving (QAA, 2023). Awareness and development of these skills within engineering programmes will benefit the student's learning in all aspects, not just in sustainable development contexts.

In addition, the current AHEP4 accreditation requirements the UK engineering programmes (Engineering Council, 2021) are enhanced compared to previous editions with respect to sustainability as well as other professional skills.

Finally, engineering graduates today will live and work in a globalised workplace and society. Many of the challenges associated with the SDGs are also global and inter-linked: personal and professional decisions in, for example, the UK will have impact around the world – consider plastic pollution of the world's oceans and its impact on marine life – so there must be wide awareness of global sustainable development challenges for the greatest chance of success.

In this context, implementation of sustainability and sustainable development teaching within engineering has been under review. As part of this, a course was developed at the University of Liverpool for year 1 students in mechanical engineering, aerospace engineering, product design engineering and industrial design, to aid in the comprehensive introduction of sustainable engineering. This is delivered within a common core module relating to Professional Skills. This course aims to bring the incoming cohort up to a common level of knowledge and understanding, recognising the cohort's diverse backgrounds and levels of knowledge and appreciation in this area. This aims to allow better participation in sustainable development learning later in the programme. The development, implementation and review of this introductory course is the focus of this implementation paper.

## COURSE DEVELOPMENT

In embedding sustainability in engineering education, various approaches have been taken. Via literature review and consideration of higher education standards and accreditation requirements, a phased, holistic approach is preferred to integrate sustainability in a programme, rather than sustainable engineering being sectioned off into one module, as noted by Hussmann, 2010. Design and project-based modules have become a natural vehicle for application of sustainable engineering in practice, as seen in Miñano, 2016, Topping, 2022.

However, students have to start somewhere. It was seen as necessary to give a broad awareness and understanding of the concepts and challenges of sustainable development and sustainable engineering near the start of students' first academic year. Only then will they be able to adequately participate in integrated sustainability curriculum content and deliver project modules with true appreciation of the multiple dimensions of 'real-world' (i.e. sustainable) engineering in terms of societal, environmental and economic considerations. After this broad introduction, later sustainability- or sustainable development-related learning can focus on specialist knowledge and analysis, and the development of the competencies thought to be required for successfully tackling the challenges of sustainable development (UNESCO, 2017).

At Liverpool, the acquisition of specialist knowledge is begun later in year 1, continuing throughout all programme years. The year 1 sustainability learning continues with an assessment focused on consumer product carbon footprint measurement using the Eco Audit tool in software Granta EduPack by ANSYS and consideration of the triple bottom line (Zaharia, 2021). Application of sustainability practices and development of sustainable development competencies occurs via project modules in years 2, 3 and 4, including the capstone projects (Topping, 2022).

For the year 1 introductory course at Liverpool, it was decided to make developments to an existing resource that had been recognised nationally and had desirable characteristics already. The resource consisted of a self-paced online course, based in the Canvas virtual learning environment, named Sustainability in Action (SiA) that was co-created with students from the University of Liverpool (University of Liverpool, 2022). It was co-created in 2020 by students from a range of disciplines with the University Careers team and the University Centre for Innovation in Education. The aim of the Sustainability in Action course was to provide an optional introduction to all incoming students of the UN SDGs. The performance and success of this course is summarised in Figure 1.



Figure 1. Summary of engagement and success of original SiA self-paced course, before customisation for engineering students (University of Liverpool, 2022)

The course was put in the context of the 5 P's of sustainable development: People, Planet, Prosperity, Peace and Partnerships (United Nations, 2015), as shown in Figure 2. Goals 1 – 6 map onto People; goals 7 – 11 onto Prosperity; goals 12 – 15 onto Planet; goal 16 onto Peace and goal 17 onto Partnerships. Goal 6 is sometimes placed under Planet also.

Within the SiA course, there are sub-modules focused on each P with method of content delivery being via infographic and Prezi presentation. Each sub-module has the following structure:

- an introduction to the SDGs and their underlying targets;
- A set of facts and figures to highlight the scale of the problems related to each SDG, and some of the work towards achieving them;
- Hot topics and case studies, relevant to those SDGs, for example renewable energy, fast fashion, climate justice: this section mainly served to define and exemplify commonly used terms within the topic of sustainable development, that new university students may not have encountered;
- A “What can you do” section;
- A research exercise: by completing all of these, students were eligible for HEAR recognition (Higher Education Achievement Report, 2015);
- A discussion forum for students to engage with each other.



Figure 2. (a) The 17 Sustainable Development Goals (SDGs), (b) The 5 P's of sustainable development. From United Nations, 2015

## Developing an Engineering-specific version

The SiA course was then developed to contextualise the SDG content for the target engineering students. The structure based around the 5 P's remained similar, with two major changes:

- Inclusion of sets of engineering sustainable development case studies in place of the 'Hot topics and case studies' sections from SiA. An infographic was created that summarised and contextualised the case studies, as well as the original case study text or media being provided;
- Replacement of the HEAR assessment exercises with credit-bearing online quizzes designed to check engagement and understanding.

The original SiA case studies and the 'What can you do' sections were still accessible to the students for their general interest but did not form part of the mandatory course track. The Prezi content was converted to new infographics to give a consistent approach; exemplar infographics are shown in Figure 3. The course material was made available in an accessible text format in addition to the infographics.

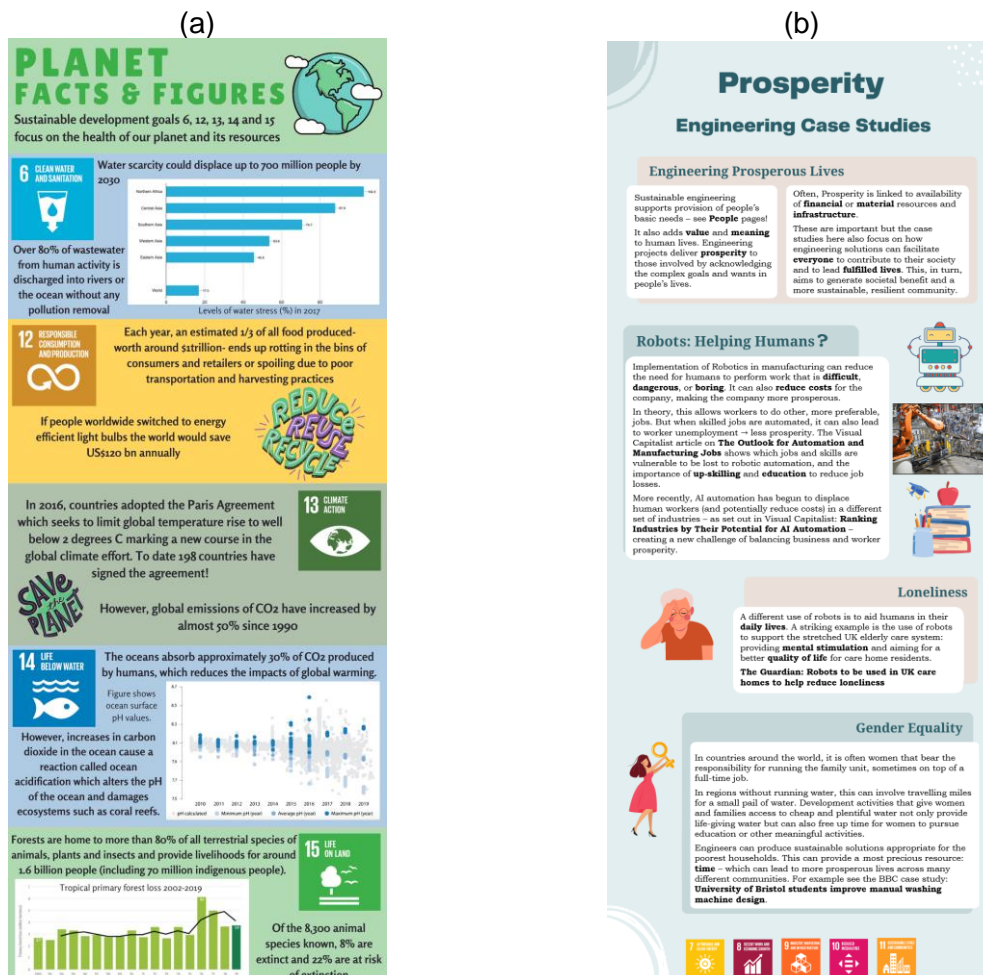


Figure 3. (a) Exemplar Infographic from the original SiA course, (b) Infographic made especially for the engineering version

Case studies were sought that could show practicing engineers and other professionals working to solve SDG issues, grouped by P. This involved research drawing on expertise of the authors to locate suitable items: ranging from YouTube videos, news articles, technical articles, industry articles, with a selection of the case studies used summarised in Table 1.

Table 1. Examples of engineering case studies used

|              |                                                                                      |                                                                                                                                                                                                                                                                           |
|--------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| People       | Farming First - How the World's Engineers Can Make Hunger History                    | Web Article:<br><a href="https://farmingfirst.org/2015/04/fethi-thabet-how-the-worlds-engineers-can-make-hunger-history/">https://farmingfirst.org/2015/04/fethi-thabet-how-the-worlds-engineers-can-make-hunger-history/</a>                                             |
| Planet       | How Singapore Fixed its Big Trash Problem                                            | Video:<br><a href="https://www.youtube.com/watch?v=r-q5V6LDxEY">https://www.youtube.com/watch?v=r-q5V6LDxEY</a>                                                                                                                                                           |
| Prosperity   | BBC: University of Bristol students improve manual washing machine design            | Web Article:<br><a href="https://www.bbc.co.uk/news/uk-england-bristol-61641123">https://www.bbc.co.uk/news/uk-england-bristol-61641123</a>                                                                                                                               |
| Peace        | How to Incorporate Social Justice into the Engineering Design Process in Seven Steps | Web Article:<br><a href="https://www.engineeringforchange.org/news/incorporate-social-justice-engineering-design-process-seven-steps/">https://www.engineeringforchange.org/news/incorporate-social-justice-engineering-design-process-seven-steps/</a>                   |
| Partnerships | Nearly all countries agree to stem flow of plastic waste into poor nations           | Web Article:<br><a href="https://www.theguardian.com/environment/2019/may/10/nearly-all-the-worlds-countries-sign-plastic-waste-deal-except-us">https://www.theguardian.com/environment/2019/may/10/nearly-all-the-worlds-countries-sign-plastic-waste-deal-except-us</a> |

In selecting suitable case studies to support the goals and 5 P's, the following criteria were used:

- **Length of resource:** around 15 case studies were used and the target time for the whole assessment was 6 hours. Therefore, resources that students could consume in several minutes were sought.
- **Media:** written articles were used but alternative formats were considered highly important to retain student interest and engagement whilst undertaking the course.
- **Location:** It is important to note that some of the SDGs are local in character, so poverty or environmental destruction in the UK will look different and have different solutions than the same in a Global South nation. For this reason, it is important to present cases to the students that cover different parts of the world.
- **Coverage of non-typical engineering topics:** to engage with students to communicate the idea that engineers can, should and do contribute to the solutions for all 17 SDGs rather than those lying close to traditional engineering applications. Providing as many diverse sustainable engineering applications as possible in the case studies can promote the widest student interest in this core topic.

A wide array of case studies was found during the search phase; all of these including those not selected for the final course have been put into a case study bank, listed by SDG, for deployment within other teaching materials. Therefore, the case study search and selection process has been highly valuable for the wider teaching teams at Liverpool.

The course as presented to the student in the Canvas environment was accessible only one page in turn. This aimed to give some structure for the students to access, understand and digest the sustainable development content in the planned order.

The assessed quizzes for every P were available once the pages for that P were each accessed but the quiz was not a prerequisite element to proceed to the next P section. In addition, the quizzes were not timed and multiple attempts were allowed although no indication of quiz scoring was given upon submission. This gave students flexibility to read and re-read the materials whilst attempting the quiz and aimed to deter a surface learning approach. In the accompanying lecture and assessment instructions, students were encouraged to spend one session on each of the 5 P's, reading the course material and answering the quizzes. Making the course “user friendly” was seen as important so as not to deter students from the start of their higher education journey in sustainability and sustainable development.

## DEPLOYMENT OF THE COURSE: YEAR 1

In the first year of student use of the engineering version of the course, two weeks were given to the students and quizzes were devised with 5 questions for each of People, Planet, Prosperity, Peace and Partnerships. The quizzes were aimed to assess the engagement with and comprehension of the course material. Quiz questions were set as to be answered solely from the provided course materials and case study articles/videos, except for the Peace quiz (the fourth out of five), whereby a short text was given (previously unseen in the course) about which the 5 questions were asked. This was utilised to vary the assessment to maintain student engagement. Questions were a mix of multiple choice, multiple answer, fill in the blank and numerical (requiring very simple calculation based on the numerical data given during the course materials). The assessment was introduced and set in the second week of the first semester, meaning it was the first university assessment that some of the students will have seen.

Some questions tested the students’ appreciation of what some of the case studies communicated about engineering in the context of sustainable development. For example, there was a fill the blank question regarding disaster relief, where the two correct answers were “working with people not for people” and “This is a ground up approach”.

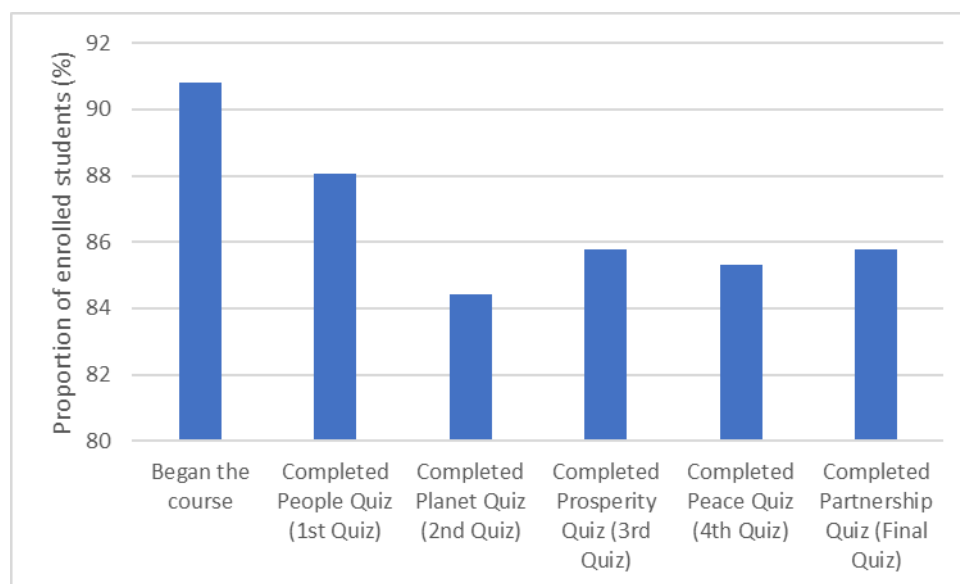


Figure 4. Summary of student engagement during the first year of delivery



Engagement with the course and the assessments can be analysed via proportion of total students enrolled on this core course that engaged with the course or completed it. This is shown in Figure 4, where it is seen engagement was overall high with some drop off of participation towards the end of the self-paced course. Nearly 10% of the students did not engage at all; this could partly be explained by the early timing of this assessment in the university calendar but this was also noted as a target for improving engagement the following year. 93% of those opening the first page of the course completed all 5 quizzes, which is seen as a successful engagement of the students' interest in this topic. There were multiple page views aggregated per student across all parts of the course, indicating that at least some students were using the learning material as intended – to read then return to when needed for quiz questions.

## FEEDBACK AND DEVELOPMENT AFTER YEAR 1

To allow for continual improvement of this course, an anonymous online course feedback survey was made available to the students once they had completed the quiz assessments. The questions focussed on perceived time spent on the course (compared to expected 6 hours), perceived extent of learning from the course and ease of navigation of the online course. Students were also given free text boxes to comment on positive experiences with the course and aspects they thought could be improved.

The course survey was responded to by just over a third of students. Of these over 70% rated 4 out of 5 or higher to the question “How much did you learn about Sustainable Development?”. Perception of amount of time spent on the course was in line with the author's expectation.

Students had feedback comments on the ease of navigation of the course and some operational improvements were made before deployment in the second year, including curtailing of some legacy content from the original SiA course that was developed for all students.

There were some encouraging feedback comments from students stating what they had enjoyed learning about and how interesting they had found the course and the case studies. This in itself implies a level of positive engagement with a significant proportion of the students. The main areas for improvement that were commented on were:

- Reducing the ambiguity or subjectivity of some of the quiz questions.
  - All quiz questions were reviewed. Questions where it was thought that we were trying to “put words into the students' mouths” were reworded. Where possible the correct answers for multiple choice questions were taken as quotes from the case study source. The Prosperity section question set was reduced in particular as ‘prosperity’ is particularly subjective. Quiz questions were reduced to 4 for Prosperity, Peace and Partnerships, but expanded to 9 for People and Planet, where more objective questions regarding the relevant data and case studies could be set.
- Improved opportunity for peer discussion of the issues that the course raised.
  - This was a feature of the original SiA course via the online discussion board, which was removed from the engineering version.
  - In the second year, a two-hour in-person instructor-guided group workshop was held to facilitate the discussion of some of the key concepts from the course.

- To include more focus on what was being done and how to solve some of the issues presented via the SDGs.
  - The infographics that summarised the case studies were reviewed and rewritten, with strong emphasis on what the engineers involved had done and why.
- Data and examples were not up-to-date.
  - Case studies were used dating back to 2011 whereby the authors had used their judgement on whether this was still relevant. However, it could be perceived by the students that these were no longer relevant. Similarly, facts and figures from the underlying original SiA course were occasionally more than 5 years old – this could be related to the period of data collection for certain data types (which may not be appreciated by students) but also to the fact that the major work to create this course was undertaken in 2020, now four years ago. The course will need ongoing refresh most years.

## DEPLOYMENT OF THE COURSE: YEAR 2

With the previously described changes responding to student experience, the course was re-run in the following academic year. Actual performance in the assessment quiz is of course relative so here it is only compared between the first and second year of operation. It should be noted that the assessment was put back by four weeks to the middle of the semester in the second year of operation, and the quiz questions were altered as previously discussed. In Table 2, are the average scores per P and overall between the two years, averaged only for those submitting the assessed quiz.

Table 2. Student assessment score (%) summary across both years of delivery

| Year | People | Planet | Prosperity | Peace | Partnerships | Overall |
|------|--------|--------|------------|-------|--------------|---------|
| 1    | 79     | 89     | 72         | 76    | 70           | 77      |
| 2    | 80     | 80     | 90         | 85    | 79           | 80      |

Overall there was a slight increase in student performance between years. The overall high average score (>70%) is deemed satisfactory at this level, particularly as it may help to encourage students to remain enthused in these topics. The slight increase in performance may be due to the improved wording of some of the questions; the quality improvements to teaching material; and the shifting of the assessment to later in the students' first semester. A similar level and trend were seen in engagement with the course, as for the first year of delivery, seen in Figure 4. In particular the loss of participation of around 5-10% of students between the first and last quiz. One potential remedy that could be considered for future years is the operation of just one longer quiz, covering all 5 P's.

## CONCLUSIONS

The development of an introductory self-paced course on sustainable development for year 1 engineering students has been outlined in this paper. To meet the objectives and required level of such a course, an existing successful in-house course for all students was modified for an engineering audience via incorporation of sustainable engineering case studies and a newly created quiz assessment to test engagement and understanding. Case studies were selected from as wide a range of sources and applications as possible to promote the enthusiasm of students in a diverse cohort.

Significant student engagement and satisfaction with the course was evaluated during the first year of delivery. Some key feedback was gathered via an anonymous feedback survey and action taken to address issues raised to improve the student experience for the next year of delivery. Performance and engagement were consistent across both years reported here.

The method of customising a generic course relating to a professional skill or area of common interest (such as sustainable development here) with case studies specific for engineering or any other subject area may be useful in implementing new learning materials in future, in a pragmatic and effective way.

Future analysis of the effectiveness of this course and similar courses could be to compare student satisfaction and engagement with student background, to ensure that the content is accessible and stimulating for all students. Follow up evaluation of students' recall of the key issues and concepts can be undertaken to assess the impact that the course has had on embedding awareness and appreciation of sustainable development, for example during later projects or specialist sustainability modules, throughout the programme.

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# **CDIO-BASED APPROACH: INTEGRATED LEARNING EXPERIENCE IN TIME SERIES MODULE**

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## **ABSTRACT**

This paper presents an integrated learning approach implemented in the Time Series module designed for Data Science students at ESPRIT School of Engineering. Crafted within the CDIO framework, the approach consists of designing and implementing end-to-end solutions for Time Series forecasting at advanced level. It addresses real-world challenges while prioritizing additional learning objectives that promote the development of personal and interpersonal skills, including collaboration, critical thinking, ethical awareness, and other relevant abilities. To ensure the grasp of theoretical and practical aspects of Time Series fundamentals, students are divided into working groups to actively engage them in their learning process through the integration of three key elements adhering to the objectives of an Integrated Learning Experience; the adoption of the Golden Circle framework, the utilization of the CRISP-DM work methodology, and the consideration of the 17 Sustainable Development Goals (SDGs). The approach delivery consists of a presentation that emphasizes all project phases. Assessment tools are designed to evaluate the methodology of work, the delivered cognitive output in addition to personal and interpersonal skills. The validation of the approach is equally reliant on students' feedback as a valuable tool. Formative and Summative evaluations of this approach have shown promising results, with students exhibiting increased confidence, competence and awareness in applying mathematical concepts to real-world scenarios. All things considered, this approach is applied to one class of students among three, and comparing final exam grades revealed an improved cognitive learning experience compared to the other two classes.

## **KEYWORDS**

CDIO framework, Integrated Learning, Personal and interpersonal skills, Sustainable Development Goals, Time Series, Standards: 1, 2, 3, 5, 7, 8, 11

## INTRODUCTION

Integrated education has gained significant attention in higher education, over the last decades, as universities recognize its potential to prepare learners for the complex challenges of the 21st century by integrating knowledge, skills, and insights from multiple disciplines (Clark, 2023; Klein, 1990; Tuselim, Muhammad, & Mai, 2020). Indeed, by fostering a more holistic and interdisciplinary outlook, integrated education helps learners become active and responsible citizens in a rapidly changing world. Several techniques and frameworks have been developed, in that way, to promote problem-solving, critical thinking, and practical learning in various fields such as, Problem/Project-Based Learning (PBL) (Woods, 2003; Bender, 2012), ChallengeBased Learning (CBL) (Johnson, Smith, Smythe, & Varon, 2009), and Conceive-DesignImplement-Operate (CDIO) framework (Crawley, 2002), to name a few. Although they share some similarities, each technique and framework has its unique features and has been implemented in different domains such as computer science (Cheung, Cohen, Lo & Elia, 2011), medicine (Barrows, 1996), civil engineering (Krogsbøll et al., 2011), etc. From the same perspective, this paper introduces an integrated learning approach implemented within the CDIO framework in a challenging subject for students: Mathematics. More precisely, the approach involves an enriched Design-Implement experience applied to the Time Series module designed for Data Science students at ESPRIT School of Engineering in Tunisia. As a matter of fact, since 2011, ESPRIT incorporates a variety of cutting-edge learning methods in its curriculum, including PBL, active learning, and more (Louati, Alaya, Khodjet El Khil, Aissa, & Bettaieb, 2016; Sifi & Alouane, 2016). While the Time Series module is already crafted with consideration for certain CDIO standards, it does not fully adhere to them in its current form. In fact, its foundation is built on fundamental mathematical concepts, complemented by practical hands-on applications to effectively analyze, model, and forecast Time Series data, where the continuous assessment and final evaluation focus mainly on cognitive acquisition. In view of the significance of Time Series analysis in diverse sectors like economics, finance, and climate science, etc, and the acknowledgement of the intricacies inherent in the underlying theory, the proposed approach provides improvements at three different levels: 1) Enhancing the cognitive acquisition for a better understanding of technical aspect of Time Series, and its significance in the field of data science. 2) Developing personal and interpersonal skills in order to enable students to comprehend the problem to be solved and the working environment in all its facets and aspects, as well as preparing them for professional engineering practice. 3) Incorporating the United Nations' Sustainable Development Goals (SDGs) (Pedersen, 2018) to encourage students to recognize their global role and foster responsibility for addressing worldwide challenges. The presented integrated approach impacts the assessment methodology rather than the teaching pedagogy. Indeed, in contrast to classical assessment, students are tasked with designing and implementing comprehensive solutions for Time Series forecasting at an advanced level. This involves delving into real-life problems and comprehending them from various perspectives, including theoretical, practical, societal, environmental aspects, and more. Divided into working groups, students were actively engaged in the learning process through the integration of three key elements adhering to the objectives of an Integrated Learning Experience. First, the adoption of the Golden Circle framework (Sinek, 2011) addresses the fundamental questions: Why are we doing this? How do we do it? and What are we doing?

It promotes effective communication and student interactions. Likewise, it cultivates creativity, critical thinking, and problem-solving skills and fosters a sense of social responsibility and ethical considerations in developing the final solution. Second, the utilization of the Cross-Industry Standard Process for Data Mining (CRISP-DM) work methodology (Wirth & Hipp, 2000), widely used in Data Science, structures the project from understanding business

objectives and data exploration to modelling evaluation and deployment. Last but not least, the consideration of the 17 SDGs, where the mapping with CDIO standards is highlighted in (Rosén et al., 2019), empowers students as responsible global citizens to align with evolving societal and professional expectations. The new pedagogical approach conforms to CDIO standards 1, 2, 3, 5, 7, 8, and 11, ensuring an enriched integrated learning experience for the Time Series module. The approach delivery consisted of a presentation that accentuates all project phases while spotlighting the integration of the three key elements: the Golden Circle framework, the CRISP-DM work methodology, and the SDGs. Furthermore, assessment tools were designed to evaluate the methodology of work, the delivered cognitive output in addition to personal and interpersonal skills. The results observed during presentations were highly satisfactory, demonstrating mastery of the technical aspect of Time Series, self-confidence, and a thorough exploration of all facets of the studied problem, coupled with an awareness of the SDGs at hand. For a more in-depth study of the reliability of the proposed approach on the cognitive level, the approach was exclusively implemented in one class of students among three. A comparison of results was conducted using the grades from a common final exam across all three classes. The statistical analysis revealed an enhanced cognitive learning experience for the class where the approach was applied, compared to the other two classes. The validation of the approach equally depended on students' feedback as a valuable tool. A questionnaire consisting of 15 questions was filled out by students to collect their opinions on the approach. Upon analyzing the results, it was observed that students generally perceived the approach to be effective and valuable, enhancing their understanding of the material. Furthermore, they reported being more engaged in the learning process. Through the questionnaire, students provided suggestions for improvement that we take into consideration in the upcoming iterations. The remainder of this paper includes a presentation of the current Time Series module, an explanation of the proposed integrated learning approach and its alignment with CDIO standards, an illustration and discussion of obtained results, and conclusions drawn in the final section.

## **TIME SERIES MODULE**

The Time Series module is intended for students in the 4th year of the computer engineering program at ESPRIT, including the Data Science and Business Intelligence Specializations. It corresponds to 2 ECTS credits and lasts for 30 hours which spread over 10 weeks. As mentioned earlier, the Time Series module has been already structured according to the CDIO framework but with insufficient focus on the cultivation of personal and interpersonal skills. It is delivered in the form of an integrated course, featuring lectures that expound on theoretical foundations grounded in mathematical concepts, with a particular emphasis on practical applications. Additionally, it is complemented by tutorials for hands-on practice. The module comprises a series of steps and tests that must be performed to successfully achieve Time Series forecasting. Consequently, the primary goal of the Time Series module is to instruct students in the analysis, modeling, and prediction of Time Series. The assessment for the Time Series module is summative. The final grade that awarded to the student is composed of 20% from the continuous assessment and 80% from the final exam grade. The final exam is administered in the form of a written test that assesses the learning outcomes defined in the module syllabus using Bloom's taxonomy. On the other hand, the continuous assessment takes the form of a project, primarily evaluating practical learning outcomes. As the pedagogical approach presented in this paper pertains to the assessment of the module, we provide more details on its current methodology in what follows. Indeed, towards the end of the module, the students, already organized into teams (typically composed of 5 to 7 students), are provided with two Time Series that present varying levels of difficulty in analysis. Each

team is tasked with navigating through all stages of Time Series analysis to achieve successful forecasting. During the final session, each group presents its analysis via an executable deliverable for a purely technical validation of the accomplished work.

## PROPOSED INTEGRATED LEARNING APPROACH

Clearly, the novel approach appears to focus solely on altering the continuous assessment method. However, underlying this change is the intention to cultivate new skills in students, which involves enhancing their understanding of technical concepts, refining the quality of their work, and developing personal and interpersonal skills, all while fostering an awareness of SDGs. Indeed, instead of receiving the data (Time Series) at the end of the module, team members receive it right from the beginning with the aim of working on it in parallel as the course progresses. Each time a step in the Time Series analysis is covered in class, it is immediately applied to the provided data. Throughout the project, students are tasked with:

1. Work in teams: It offers numerous advantages for students, including the development of essential skills such as problem solving and delegation, enhanced learning, improved communication, increased participation, deepening of knowledge, and social support.  
–
2. Development of an end-to-end solution for the provided Time Series forecasting: By engaging in the complete process, students gain practical insights into the complexities of real-world problem-solving, while applying theoretical knowledge to tangible scenarios. This approach fosters a deeper understanding of the subject matter, encourages critical thinking, and cultivates problem-solving skills. Additionally, it promotes a holistic perspective by integrating theoretical concepts with practical applications, contributing to a more comprehensive and meaningful learning experience.
3. Integration of the Golden Circle framework to answer the three questions “What?” “Why?” and “How?”. It brings clarity to the problem’s purpose (What?), motivates intrinsically (Why?), and guides strategic problem-solving (How?). This enhances the learning experience and fosters the development of personal and interpersonal skills among students. Effective communication and collaboration in conveying the “What,” “Why,” and “How” contribute to their comprehensive skill set.
4. Implementation of the CRISP-DM methodology: It supports a holistic study of the underlying problem, fostering a deep understanding of the entire data science project. This approach ensures a systematic and thorough examination, contributing to a more insightful analysis and solution development. As well, it promotes systematic problem-solving, teamwork, and communication skills, leading to a comprehensive educational experience.
5. Identification of the associated SDGs with the studied problem: It fosters a holistic and socially responsible approach to data analysis. It adds a layer of ethical consideration and aligns technical solutions with broader global objectives. By examining the involved SDGs in the Time Series project, the analysis gains relevance to societal challenges, contributing to responsible and purpose-driven data science.



This integration encourages students to recognize the broader implications of their work and promotes a mindset of ethical and sustainable problem-solving.

6. Summarizing all previous points in an English (foreign language) oral presentation during the last session to evaluate the work performed. Unlike traditional evaluation solely focused on cognitive acquisition, this new approach considers all aforementioned points.

With the new approach, it becomes evident that the Time Series module aligns more closely with the CDIO standards outlined below, demonstrating a stronger adherence to their principles.

**Standard 1:** The new approach consists of a Design-Implement experience that focus on the development of personal and interpersonal skills.

**Standard 2:** The new approach adds new learning outcomes related to personal and interpersonal skills such as engineering reasoning, awareness of professional ethics, etc.

**Standard 3:** With the new approach, the curriculum is crafted to feature mutually reinforcing disciplinary courses, with a clear strategy for blending personal and interpersonal skills.

**Standard 5:** Students design and implement an end-to-end solution at an advanced level by integrating personal and interpersonal skills.

**Standard 7:** The new approach enables a holistic exploration of the problem within its complete environment, addressing technical aspects, SDGs, environmental considerations, and more. This integration of theory and practice, through hands-on experiences, allows students to delve into various facets of the problem.

**Standard 8:** Students were engaged actively in discussions, collaboration, thinking, problem-solving, and hands-on activities, shifting away from passive information transmission.

**Standard 11:** The assessment involves a team presentation that emphasizes various skills, including disciplinary, personal, and interpersonal competencies.

## RESULTS AND DISCUSSIONS

### *Exam grades analysis*

Using identical course materials and teaching pedagogy across 3 randomly selected classes of students; Class 1, Class 2, and Class 3, out of 9 in the Data Science specialization, the new integrated experience was implemented exclusively in Class 1. To assess its impact on achieving the learning outcomes, described in the Time Series module syllabus, we conducted a comparison using the final exam results. This exam was common to all 9 classes of students and administered during the main exam session in May 2023. The performance outcomes of students are illustrated in Table 1 and Figure 1, where best results are associated with the Class 1. Indeed, the Table 1 shows that the greater grades mean 10.86 is obtained for Class1 compared to 9.83 and 10.18 for Class2 and Class3, respectively. In addition, the highest estimate median 11.25 is observed with the Class1. For that same value 11.25, the percentage of grades above this latter is 55,55% for Class1, compared to 28.13% and 36.67% for Class2 and Class3, respectively. A noteworthy observation, through Figure 1 where results are

represented in percentage, is the prevalence of scores between 10 and 15 (indicating that the module is validated), constituting approximately 67% in Class1 compared to around 47% and 57% in Class2 and Class3, respectively. Upon closer examination of these variations and their implications, it becomes clear that the integrated teaching method positively influenced students' performance and enhanced the acquisition of learning outcomes related to disciplinary knowledge.

Table 1. Statistics of obtained grades for the three classes, Where  $N_s$  and  $N_{pe}$  indicates the number of students and the number of students that passed the final exam, respectively

|         | $N_{pe}$ | $N_s$ | mean  | standard deviation | minimum | median | maximum |
|---------|----------|-------|-------|--------------------|---------|--------|---------|
| Class 1 | 27       | 29    | 10.86 | 2.50               | 5.25    | 11.25  | 15      |
| Class 2 | 32       | 32    | 9.83  | 2.25               | 5.75    | 9.75   | 14.25   |
| Class 3 | 30       | 31    | 10.18 | 2.40               | 4.75    | 10.63  | 14.25   |

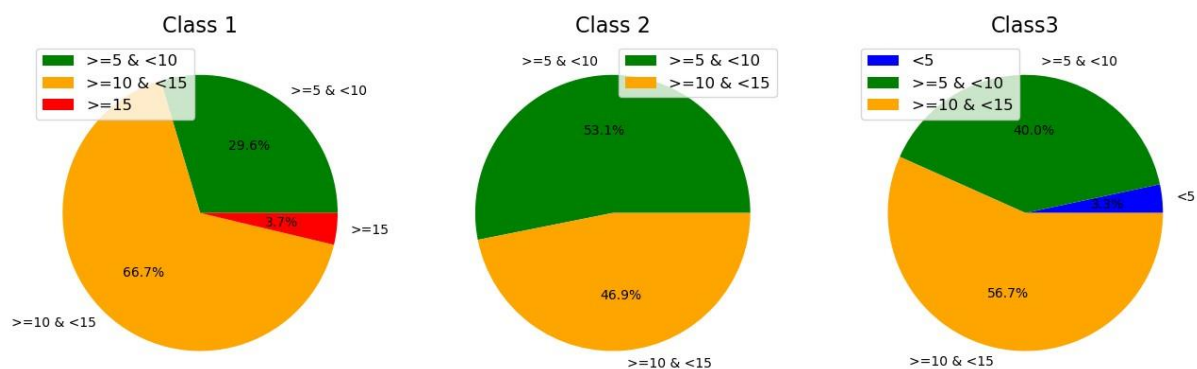


Figure 1. The three classes' grades categorized into 4 groups: strictly below 5 (in blue), between 5 and 10 strictly (in green), between 10 and 15 strictly (in orange), and above 15 (in red)

### Students feedback analysis

In order to gather additional information about the integrated approach, we developed a questionnaire consisting of the following 15 questions (**Q1** to **Q15**), in a variety of formats, including open-ended, Likert-scale and multiple-choice questions. These questions were designed to elicit students' views on 5 main aspects: Disciplinary knowledge (**Q1**, **Q2**, and **Q15**), Engineering skills (**Q3**, **Q4**, **Q8**, and **Q6**), SDGs (**Q7**, and **Q5**), Integrated learning approach (**Q9**, **Q10**, **Q13**, and **Q11**), and Overall Experience (**Q12**, and **Q14**).

**Q1:** To what extent did the integrated approach contribute to your understanding of the technical aspects in Time Series?

**Q2:** How well did the integration of end-to-end solutions for Time Series forecasting contribute to the understanding of the module objectives?

**Q3:** How effective was the Golden Circle Framework in deepening your overall understanding of the project?

**Q4:** To what extent do you think this approach has contributed to the development of your interpersonal skills, (such as communication, leadership, teamwork. . .)?

**Q5:** Did the integration of the SDGs in the Times Series module raise your awareness towards the principles of sustainability and society?

**Q6:** Was the integration of CRISP-DM methodology helpful in organizing and managing your project properly?

**Q7:** How do you rate the overall integration of SDGs in the time series module?

**Q8:** To what extent do you think this approach has contributed to the development of your personal skills (e.g., critical thinking, problem solving, work ethics. . .)?

**Q9:** How efficient is this approach in learning Time Series?

**Q10:** How satisfied are you with the integrated learning approach in teaching Time Series?

**Q11:** To what extent do you consider the teacher's supervision necessary for the task at hand during each session?

**Q12:** How do you rate your overall learning experience in the Time Series module?

**Q13:** Were there any challenges with this integrated learning approach?

**Q14:** Do you have any recommendations related to the integrated learning approach in Times Series teaching?

**Q15:** What factors contributed to improving your understanding of the various technical aspects covered in the module? Tick all that apply. 1) Integration of the Golden Circle: The What? Why? and How? method. 2) Use of the CRISP-DM methodology to conduct the project. 3) Teamwork: discussions and interactions. 4) Integration of the SDGs : being aware of professional and societal challenges. 5) Development of an end-to-end solution. 6) Other.

Over 29 students of Class1, 25 ones filled out the questionnaire under google forms. In figure 2, we represent the results of the first 12 questions given on a 5-point likert scale, where a rating of 1 signifies the lowest evaluation, while a rating of 5 indicates the highest evaluation. Throughout this figure, we can easily see that orange and red colors are dominating which are associated to answers 4 and 5, respectively. These results confirm the overall satisfaction of students regarding the new approach. Especially, with the implementation of an end-to-end solution for Time Series forecasting, where students showed a great appreciation in Figure 2, Q2 with 88% of satisfaction. These results suggest that the holistic approach of learning has positively impacted students' technical understanding of the subject, fostering the development of personal and interpersonal skills while fully grasping the underlying studied problem. Additionally, the majority of responses for most questions have an average value greater than 4, excluding questions **Q4**, **Q5**, and **Q7**. These questions focus on developing interpersonal skills and integrating SDGs, where the average values are 3.8, 3.84, and 3.68, respectively. This suggests that some students may not yet fully appreciate their importance. This issue

becomes even clearer when examining students' responses to **Q15**, given by Figure 3, where students indicate the success factors of the new approach, chosen from a predetermined list of factors (see **Q15**), with the possibility of adding others. Key components of the integrated approach were mentioned by students with percentages above 64%, except for the integration of SDGs, which is cited by just 48% of students. With full knowledge, it might be beneficial to emphasize the importance of SDGs further in upcoming iterations.

To empower students to share their critiques, we incorporated two open-ended questions in the questionnaire: **Q13** and **Q14**. Besides recommendations that indicate a general consensus among students who found the integrated approach effective, different challenges has been mentioned, such as time constraints and preferences for quantity over quality, indicating potential areas for improvement. Addressing them could further enhance the overall approach's effectiveness. Another drawback that has been well highlighted by **Q11** concerns the necessity of the teacher's Supervision. Some students may feel the need for more guidance, emphasizing the importance of flexibility in teaching approaches to cater to individual needs.

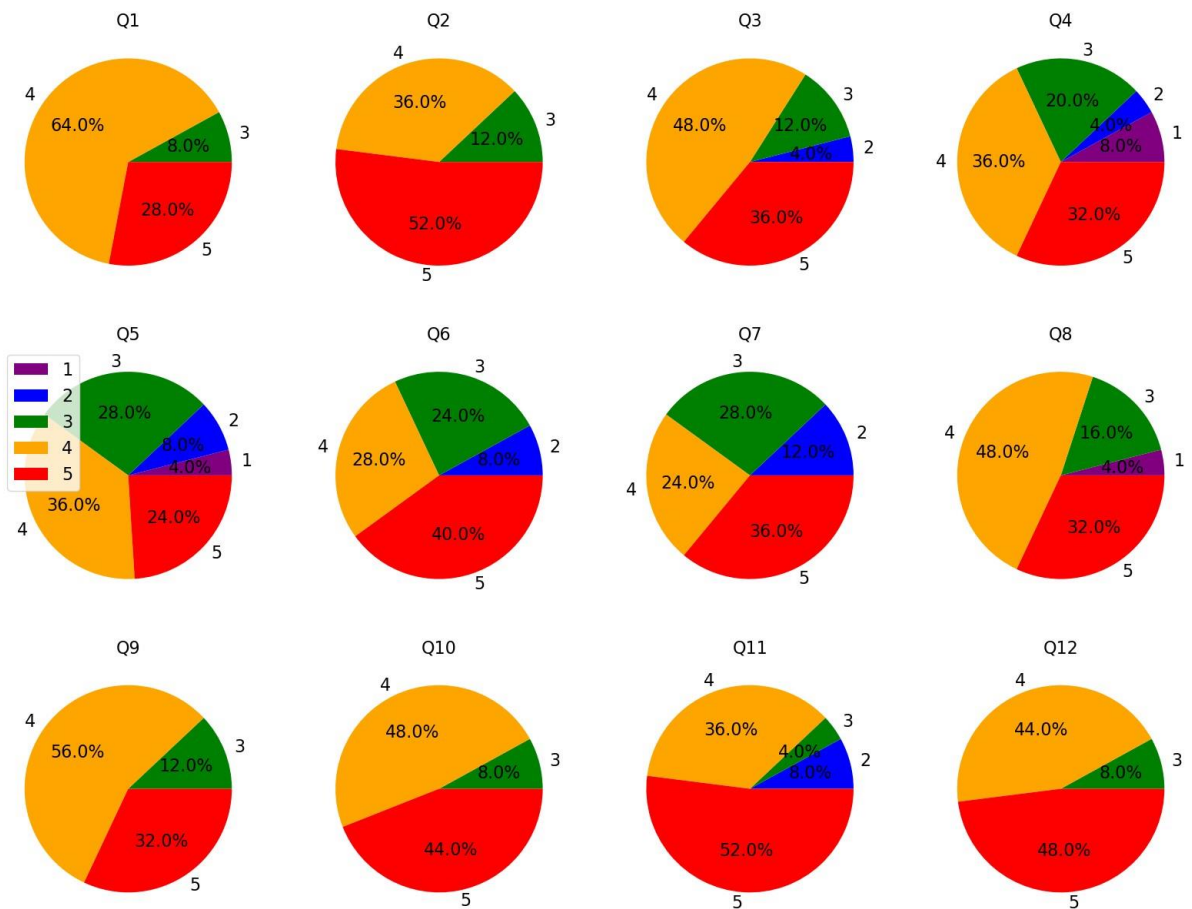


Figure 2. The students' feedback

## CONCLUSIONS

This paper introduces a robust pedagogical approach implemented within the Time Series module for Data Science students at ESPRIT School of Engineering. Rooted in the CDIO

framework, the approach seamlessly integrates disciplinary knowledge acquisition with the cultivation of personal and interpersonal skills.

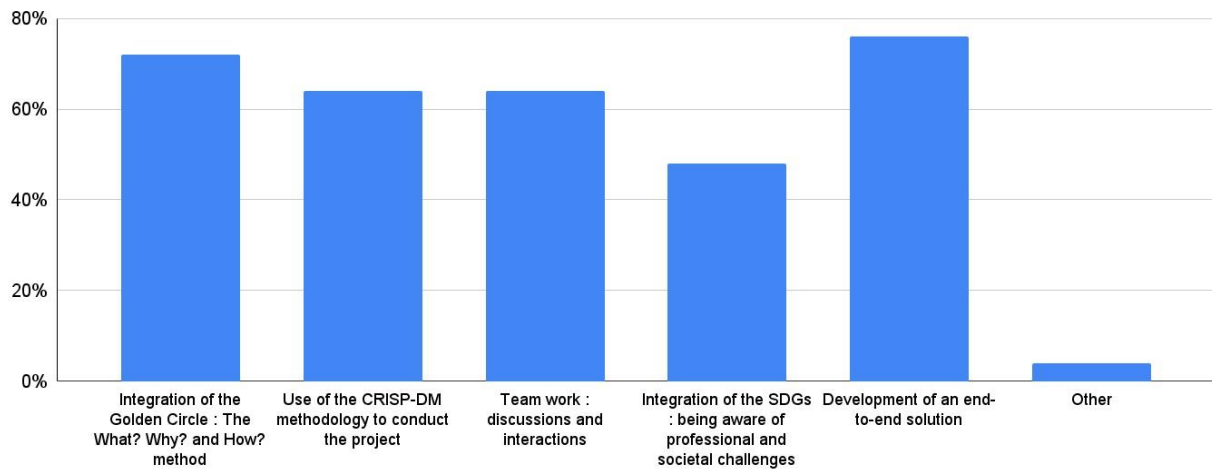


Figure 3. Students' responses to Question 15

Validation supported by students' feedback affirms its efficacy. Comparative analysis reveals improved cognitive learning experiences, suggesting broader application in educational contexts. As industries increasingly value not only technical expertise but also collaborative abilities and ethical considerations, this approach prepares students for a well-rounded professional journey. Looking ahead, this pedagogical approach holds promising perspectives for shaping the education landscape in the context of Time Series analysis and beyond. Its adaptability to different classes, subjects, or institutions holds transformative potential in how students engage with and apply their knowledge. As the education landscape evolves, this approach serves as a beacon for incorporating not just technical proficiency but a holistic set of skills that will empower students to thrive in the ever-changing world of Data Science and beyond.

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# QUANTUM LEARNING: INSIGHTS FROM CASE STUDY IN AI ENGINEERING EDUCATION

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## ABSTRACT

This communication examines the integration of quantum computing into AI engineering education, with a specific focus on aligning the course design with CDIO Standards. Authored by the module's instructor and three participating students, it narrates the experience of integrating Quantum Computing into the curriculum and the interdisciplinary knowledge it encompasses. The course curriculum drew from essential scientific domains such as linear algebra, differential and integral calculus, statistics, group theory, quantum mechanics, electromagnetism, information theory, algorithmic thinking, computational complexity, and numerical simulation. These domains are traditionally part of the foundational studies in an undergraduate engineering program and were effectively utilized as building blocks for understanding Quantum Computing. The paper explores the idea of introducing this novel field early in the undergraduate engineering cycle, using it as a cornerstone that ties together various fundamental and specialized fields of knowledge. A survey conducted among the students indicated a strong agreement that the Quantum Computing course fits naturally within the earlier stages of their engineering education, allowing for a practical application of many concepts learned during this period. The paper demonstrates the feasibility and benefits of employing Quantum Computing as a comprehensive educational tool. It argues that such integration aligns with and enhances the core objectives of undergraduate engineering programs, providing a cohesive learning journey from fundamental principles to advanced applications. The student survey results reinforce this proposition, suggesting that such a course could serve as an effective pedagogical strategy to consolidate and apply the broad spectrum of topics covered in the engineering curriculum.

## KEYWORDS

Quantum Computing, Pedagogy Engineering Education, Curriculum Development, Interdisciplinary Teaching, CDIO Standards: 2,4,5,7,8,9,11

## INTRODUCTION

Quantum computing is an emerging area that combines elements of physics, mathematics, and computer science (Kaswan, 2023). It is considered as a remarkably interesting and challenging area in science and engineering, with many potential uses in different fields (Amin et al., 2019). Indeed, this field provides a wide range of application opportunities, including optimization, machine learning, and simulations of chemical, physical, and biological systems (Pal & al., 2023) and (Hidary, 2019). It contributes significantly to telecommunications and information transmission, advancing medical technologies, and developing new materials to tackle health and environmental challenges (Aithal, 2023). A 2017 Forbes Magazine article by Marr emphasized the transformative impact of quantum computers across various sectors (Marr, 2017). Moreover, this domain has recently witnessed rapid progress, making it one of the fastest-evolving sectors within science, technology, engineering, and mathematics (STEM) (Majumdar, 2023). This advancement is receiving significant financial support from governments, funding agencies, and businesses. They aim to fully utilize the capabilities of quantum computing by making advancements in both the machinery and software aspects.

Quantum Computing (QC) has the potential to play a vital role in secure communication networks through quantum cryptography, enhancing data encryption, and security. It is instrumental in optimizing network design and traffic management, potentially transforming the telecommunications industry (Muruganatham, 2020). In material science, it aids in discovering new materials, and in finance, it assists in complex risk analysis and portfolio optimization (Orús, 2019). The field's multidisciplinary nature makes it an ideal subject for engineering education frameworks that emphasize practical, real-world applications and interdisciplinary learning. Indeed, quantum computing demonstrates the relevance of complex theoretical concepts in tangible applications, resonating with CDIO Standard 3: Integrated Curriculum. This mixing of different areas of knowledge helps gain a deep understanding, which is important for today's engineering problems (Aithal, 2023).

The complexity of quantum computing, demanding both theoretical and practical knowledge, aligns well with CDIO Standard 2: Learning Outcomes (CDIO, 2024). Indeed, it requires a curriculum that cultivates a deep understanding of basic principles while also improving skills in problem-solving, critical thinking, and innovation (Hallenga-Brink, 2017). Thus, quantum computing is not merely a subject of study but an all-encompassing educational approach that integrates smoothly with the CDIO standards and syllabus, especially when considered alongside the various disciplines that form its foundation. The integration of QC into AI engineering education, as narrated in this paper, is an example of how multidisciplinary knowledge can enrich the learning experience, in line with the CDIO standards.

## CONTEXT OF QUANTUM COMPUTING IN MODERN EDUCATION

The rising interest in quantum technologies has led to a demand for a well-trained workforce across various sectors. Universities are responding by introducing quantum computing programs and courses at both undergraduate and graduate levels (Hidary, 2019). Moreover, QC has captivated the attention of academia and industry alike (Carberry, 2021). Particularly in AI engineering, where innovation and adaptability are key, the inclusion of QC education provides a holistic view of both theoretical and practical aspects of modern technology (Fernández Pérez, 2022). QC is a melting pot of various fields, each contributing a unique perspective and essential skills. Mathematics, with its branches like linear algebra and calculus, forms the foundation upon which quantum theories are built. Algorithmics and



programming bridge the gap between theoretical concepts and practical applications. Quantum mechanics and classical physics provide the necessary scientific background, deepening the understanding of Quantum Computing's operational principles. In addition, complexity theories offer insights into the computational potential and limitations of quantum algorithms (Njeri, 2023). By encapsulating various disciplines, QC education allows teachers to build integrated learning experience (Cheah, 2021) according to the 7th CDIO standard (CDIO, 2024).

This paper is a narrative of a case study of a QC course offered to final-year AI engineering students. Authored by the module's instructor and participating students, it sheds light on the experience and impacts of integrating such a multidimensional subject into the engineering curriculum. Through this study, we aim to demonstrate the feasibility and benefits of employing QC as a comprehensive educational tool, arguing for its inclusion right from the initial stages of undergraduate engineering programs.

## **CASE STUDY OVERVIEW**

### ***Background of the Course***

This QC course is planned for final-year-students (5<sup>th</sup> year in a five years engineering program) in the AI class. We aim to teach them about the basics and uses of quantum computing, especially in machine learning. It covers different scientific areas for a wide understanding of QC. It broadens students' horizons in AI and machine learning advancements by integrating quantum computing into the comprehensive AI engineering curriculum, bridging the gap between fundamental engineering principles and cutting-edge computational technologies.

### ***Interdisciplinary Curriculum Components***

The curriculum merged various subjects, each contributing to forming a full understanding of QC:

*Mathematics:* Topics like linear algebra and calculus were pivotal in understanding quantum algorithms and their theoretical foundations.

*Algorithmics:* Students explored the development and analysis of quantum algorithms, gaining insights into their computational complexity and efficiency.

*Python Programming:* Practical sessions using Python, with libraries like Qiskit, allowed students to implement and simulate quantum algorithms, translating theory into practice.

*Quantum Mechanics:* Fundamental concepts of quantum mechanics were essential for grasping the operational principles of quantum computers.

*Classical Physics:* A solid grounding in classical physics helped students appreciate the contrast and evolution from classical to quantum computing.

## **Methodology and Teaching Approach**

The course employed a blend of interactive lectures, lab sessions, and project-based learning. Students were encouraged to participate in discussions, work on group projects, and engage in hands-on lab activities, enabling them to apply theoretical knowledge to experimentation on simulators.

## **Student Engagement and Learning Outcomes**

To evaluate the course's impact, a survey featuring open-ended questions was administered to the 36 students who participated. The students' responses were not collected in one shot, but by interview during the 7 weeks duration of the course. The feedback was positive overall, with students highlighting the course's role in solidifying their understanding of previously learned concepts and their relevance. The survey also revealed that students appreciated the interdisciplinary nature of the curriculum, which provided them with a more integrated and cohesive learning experience. The learning outcomes met expectations, with students demonstrating a comprehension of QC principles and their applications in AI engineering.

### **Course Objectives:**

- *Understand the Fundamentals of Quantum Computing:* Grasp the basic principles of quantum mechanics as they apply to computing.
- *Learn Quantum Algorithms:* Explore key quantum algorithms and their implications in computing.
- *Application in Machine Learning:* Understand how quantum computing can revolutionize machine learning.
- *Hands-On Experience:* Gain practical skills through simulations and programming exercises in a quantum computing environment.
- *Future Perspectives:* Discuss the potential and challenges of quantum computing in machine learning.

### **Intended Learning Outcomes (ILOs):**

- *Explain Key Quantum Concepts:* Describe quantum bits, superposition, and entanglement.
- *Demonstrate Understanding of Quantum Algorithms:* Such as Shor's algorithm, Grover's algorithm, and quantum Fourier transform.
- *Apply Quantum Principles in Machine Learning:* Implement basic quantum machine learning algorithms.
- *Develop Quantum Programs:* Use quantum programming languages for simple tasks.
- *Critically Analyze the Impact of Quantum Computing On future developments in machine learning and AI.*

## **ALIGNMENT OF THE MODULE WITH CDIO STANDARDS 3.0**

The relevant CDIO standards (CDIO, 2024) related to the course Quantum Computing, considering its objectives and structure, are as follows:

### *CDIO Standard 2: Learning Outcomes*

This standard is crucial as the course has specific Intended Learning Outcomes (ILOs) that encompass understanding quantum computing concepts, developing quantum programming skills, and applying these in the context of machine learning.

### *CDIO Standard 3: Integrated Curriculum*

The course integrates fundamental knowledge in quantum mechanics with advanced quantum computing and machine learning concepts, providing an interconnected and comprehensive learning experience.

### *CDIO Standard 5: Design-Implement Experiences*

The Quantum Computing (QC) course aligns effectively with CDIO Standard 5, which emphasizes the importance of design-implement experiences in engineering education. This alignment is evident through the course's structure and its integration of practical, hands-on experiences that progressively build in complexity.

### *CDIO Standard 7: Integrated Learning Experiences*

This standard is relevant due to the course's combination of theoretical knowledge with practical applications, ensuring that students can apply their academic learning in real-world contexts.

### *CDIO Standard 8: Active Learning*

Given the course's interactive format, including quizzes and programming exercises, it aligns with active learning methodologies, encouraging student engagement and deeper understanding.

### *CDIO Standard 11: Learning Assessment*

The diverse assessment methods (quizzes, programming assignment, and final project) in the course are in line with this standard, providing a comprehensive evaluation of the students' understanding and skills.

The above standards are particularly pertinent due to their emphasis on learning outcomes, integrated and active learning approaches, practical application of knowledge, and comprehensive assessment methods, all of which are key components of the course syllabus.

## **RELEVANCE OF THE MODULE WITH CDIO SYLLABUS 3.0**

The quantum computing (QC) module in AI engineering education aligns seamlessly with the comprehensive framework of the CDIO Syllabus 3.0, addressing multiple aspects of engineering education and professional development.

## ***Fundamental Knowledge and Reasoning***

### *1.1-1.3 Knowledge in Mathematics, Sciences, and Advanced Engineering*

The QC module deeply integrates with sections 1.1 to 1.3 of the CDIO syllabus. It encompasses essential mathematics and sciences, notably linear algebra and quantum mechanics, and extends to advanced engineering concepts critical for understanding quantum algorithms and computational complexity. This rigorous academic foundation is vital for developing students' engineering reasoning and problem-solving skills.

## ***Personal and Professional Skills and Attributes***

### *2.1 Engineering Reasoning and Problem Solving*

Sections 2.1.1 to 2.1.5 of the CDIO are particularly addressed through the module's focus on problem identification, modeling, and analysis within the complex domain of QC. Students learn to navigate uncertainties inherent in quantum systems, enhancing their analytical skills and ability to formulate classical computing problems in the framework of QC.

### *2.2 Experimentation and Knowledge Discovery*

The module encourages students to engage in experimentation (2.2.3) and hypothesis testing (2.2.4), particularly through lab sessions and Python programming exercises. This hands-on approach develops a deeper understanding of QC concepts and their practical applications.

### *2.3-2.4 System Thinking and Attributes*

The interdisciplinary nature of the QC module cultivates system thinking (2.3.1-2.3.4), encouraging students to view QC within the larger context of engineering systems. It also enhances attributes like creative and critical thinking (2.4.4-2.4.6), preparing students for the complexities of actual engineering challenges.

## ***Interpersonal Skills: Collaboration, Teamwork, and Communication***

### *3.1 Teamwork and Collaboration*

The collaborative projects within the module promote teamwork (3.1.1) and multi-perspective collaboration (3.1.2), reflecting the interdisciplinary essence of QC. Engaging with peers from various backgrounds encourages a comprehensive approach to problem-solving.

## ***Conceiving, Designing, Implementing, and Operating Systems***

### *4.1-4.6 The Innovation Process*

The QC module directly contributes to students' understanding of the entire innovation process (4.1-4.6), from conceiving and designing quantum algorithms to implementing and operating them. This comprehensive approach aligns with the CDIO's emphasis on practical, real-world engineering experiences.

## ***The Extended CDIO Syllabus: Leadership, Entrepreneurship, and Research***

### ***5.1-5.3 Leadership, Entrepreneurship, and Research***

Finally, the QC module touches upon leadership (5.1), entrepreneurship (5.2), and research (5.3). Students are encouraged to lead innovative projects, explore entrepreneurial aspects of QC technology, and engage in research, preparing them for leadership roles in the engineering sector.

The above analysis shows that QC module is a robust embodiment of the CDIO Syllabus 3.0, promoting a comprehensive, interdisciplinary, and practical engineering education.

## **FEEDBACK AND SURVEY FROM STUDENTS ON QUANTUM COMPUTING COURSE**

This section collates and analyzes responses gathered from students, offering insights into their experiences and perceptions of the course's structure, content, and impact on their academic and professional outlook.

### ***Summary of Student Feedback***

#### ***Personal Insights and Expectations***

Students entered the course with diverse expectations, ranging from anticipations of hands-on experiences with quantum computers to apprehensions about the course's complexity. As the course progressed, many realized its theoretical focus and the importance of foundational knowledge in quantum computing.

#### ***Interdisciplinary Knowledge***

A recurring theme in the feedback is the appreciation of the interdisciplinary nature of the course. Students highlighted the integration of concepts from physics, linear algebra, and statistics, which enriched their understanding of quantum computing and demonstrated the practical application of these disciplines.

#### ***Early Integration of Quantum Computing Education***

Opinions varied on the early introduction of QC in undergraduate education. While some saw it as advantageous for future technological readiness, others expressed concerns about its complexity for early-stage students. The consensus pointed towards its integration in the 2nd to 3rd undergraduate years, aligning with the development of foundational knowledge in relevant scientific domains.

#### ***Course Impact on Engineering Curriculum***

The QC course was perceived as a significant addition to the engineering curriculum, highlighting a deeper understanding of interdisciplinary connections. It expanded students' perspectives on how different scientific methods can converge in emerging fields like quantum computing.

### *Long-term Educational Impact*

Students acknowledged the potential of quantum computing in reshaping AI and its applications. The course promoted a long-term interest in quantum technologies and their role in future AI advancements.

### ***Analysis of Student Feedback***

#### *Themes and Patterns*

Common themes include the need for more practical engagement, early integration of QC education, and the course's role in broadening interdisciplinary understanding. Students expressed a desire for a more in-depth exploration of quantum computing concepts and practical applications.

#### *Course Strengths and Areas for Improvement*

The course was praised for its comprehensive interdisciplinary approach and theoretical foundation. However, students suggested improvements such as increased hands-on experiences, more in-person teaching, and expanded coverage of advanced topics.

### ***Recommendations for Course Enhancement***

1. **Enhanced Practical Experience:** Incorporate more laboratory sessions or simulations to provide hands-on experience with quantum computing concepts.
2. **Interdisciplinary Integration:** Continue to strengthen the connection between QC and other scientific domains, through collaborative projects or interdisciplinary workshops.
3. **Early Course Introduction:** Consider introducing fundamental QC concepts in earlier undergraduate years, aligning with the development of related mathematical and physical knowledge.

The student feedback highlights the QC course's success in developing interdisciplinary understanding and curiosity in quantum computing. However, it also underscores the need for more practical engagement and earlier exposure to QC concepts. These insights are important for refining the course to better meet students' educational needs and interests.

## **CONCLUSION**

The case study from ESPRIT School of Engineering, focusing on the inclusion of quantum computing in the AI engineering curriculum, reveals an educational strategy aligned with the CDIO Standards. The course's design, which integrates quantum computing concepts, reflects a careful consideration of the CDIO Syllabus: It addresses several key areas, including technical knowledge and reasoning, personal and professional skills, and attitudes essential for future engineers. The students' feedback indicates that this methodical approach was effective in enhancing their understanding of the intersection between mathematics, physics, quantum computing and AI. The study also shows the potential benefits of incorporating quantum computing into engineering education early. Indeed, introducing quantum computing early in the curriculum aligns seamlessly with undergraduate studies, as it leverages the math and physics knowledge gained in earlier years. This approach offers an integrated learning

experience, enriching the curriculum with practical and theoretical elements that align closely with the CDIO Standards while addressing the CDIO Syllabus.

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# **STUDY OF STUDENTS' SELF-DIRECTED LEARNING COMPETENCIES AT SINGAPORE POLYTECHNIC**

**Helene Leong, Mei Yee Chan, Gavin Bryan Lee, Kian Chee Loh, Chong Siew Kee**

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## **ABSTRACT**

A key goal of higher education is to prepare graduates to be self-directed lifelong learners imbued with the ability to continuously learn, unlearn and relearn to keep pace with the rapidly transforming industry needs. Singapore Polytechnic has implemented Flipped learning in all its programmes. Studying a flipped learning module requires students to use self-directed learning strategies to review and comprehend the learning materials before class. As a preliminary check on the impact of implementing Flipped Learning on students' learning, a dipstick survey to study students' SDL competences was administered to all students at the end of the academic year in Feb 2023. The objective of the survey was to ascertain students' self-directed competencies in terms of their self-efficacy for learning and their use of different learning strategies. Two components of the Motivated Strategies for Learning Questionnaire, the 'Self-Efficacy for Learning & Performance' (SE) and 'Metacognitive Self-Regulation' (MSR) scales were adopted for the survey. The findings from the survey showed that students perceived themselves as confident of learning concepts taught in their flipped learning modules and believed that they have the ability to do well. They adopted strategies like self-assessment and questioning that helped them monitor how well they understood the material. The paper will present the analysis of the quantitative data findings of the study and the learning and future work that emerged. The study aims to contribute to the ongoing discussion on the importance of SDL in higher education and provide valuable insights for educators and policymakers.

## **KEYWORDS**

Self-directed Learning, Flipped Learning, Assessment, Self-Efficacy, Metacognitive Self-regulation, Standards 8, 11

## INTRODUCTION

Globalisation, new technologies, environmental concerns, economic and political uncertainties are impacting the way we live and work. According to the 2023 World Economic Forum's Future of Jobs Report, the world of work is set to go through major changes in the next 5 years where 23% of jobs will be disrupted, with some eliminated and others created (WEF, 2023). Technologies like digital platforms and apps, e-commerce and digital trade, and AI are expected to result in significant labour market disruption and job displacement and will be key drivers of business transformation. It is thus important that students and graduates entering the workplace know how to learn, how to adapt in changing circumstances, and know how to be independent and take the initiative when required. Self-directed learning (SDL) prepares students for these challenges.

A key goal of higher education is to prepare graduates to be self-directed lifelong learners with the ability to continuously learn, unlearn and relearn to keep pace with the rapidly transforming industry needs. It is recognised as one of the critical 21st Century skills for life and career (Partnership for 21st Century Skills, 2007). In the CDIO syllabus, the skills of self-directed learning are reflected in 2.4.6 (Self-awareness, Self-reflection, Metacognition and Knowledge Integration), 2.4.7 (Learning Agility, Lifelong learning and Educating) and 2.4.8 (Time and Resource Management) in the category "Attitudes, Thought and Learning".

In SP, "Self-directed Learning and Personal Responsibility" is one of the six graduate attributes that the institution aims to develop in its students. The institution has defined this graduate attribute as:

"Ability to manage own learning, learn how to learn, seek opportunities for lifelong learning, and achieve work and life goals while maintaining overall well-being." (Singapore Polytechnic, 2020).

With the various definitions in mind, SP proposed a SDL framework (Figure 1) that involves 2 key components (Leong et al, 2019):

1. Motivational or mindset component which includes the students' motivation and self-belief about themselves as learners; and
2. Cognitive or skills set components which includes the cognitive and metacognitive learning strategies that learners use.

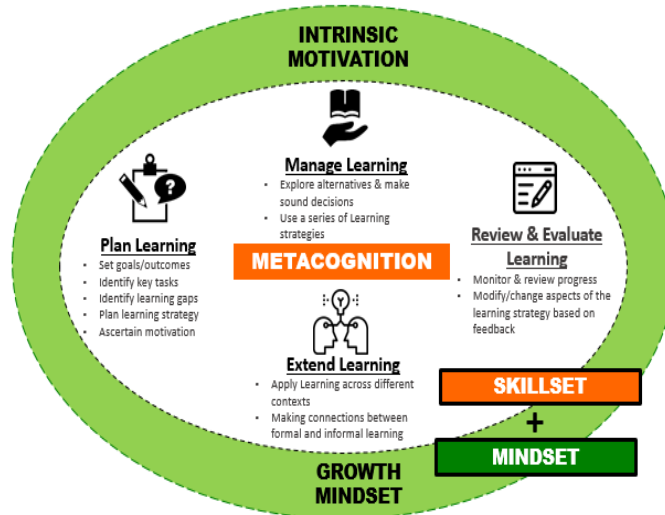


Figure 1. Singapore Polytechnic's Self-directed Learning Framework

According to Brandt (2020), pedagogical approaches promoting self-directed learning typically support choice and personalisation, agency, responsibility, collaboration and peer support. Such pedagogical approaches include project-based learning, self-assessment and online and distance learning. In these approaches, the teacher plays a facilitating and scaffolding role while the student carries out personalised activities to develop and demonstrate SDL competencies. Tan & Koh (2014) wrote that “for self-directed learning experiences to be effective, teachers need to carefully structure the task environment to provide sufficient scope for students’ self-direction” (p. 16-17) and one of the ways highlighted was the case of flipped learning. Abeysekera & Dawson (2014) also proposed that flipped learning might improve student motivation and help manage cognitive load.

In SP's implementation of Flipped Learning, all face-to-face lectures are converted to self-paced asynchronous online lesson packages. Studying a flipped learning module requires students to use self-directed learning strategies to review and comprehend the learning materials before class. Quizzes are embedded into these lesson packages to check students' understanding as well as to get them to reflect on their learning as they progressed. The students' quiz attempts provide lecturers with data to differentiate their tutorial activities for different learning abilities. During face-to-face tutorials, students actively apply their knowledge in lesson activities customised to their level of understanding and learning abilities. For example, lecturers could conduct mini-lectures on topics that majority of students found difficult or divide the class into groups to carry out differentiated team-based learning activities.

In addition to the Flipped Learning approach, in some modules, lecturers teach the skills of SDL explicitly. Wong and Cheah (2022) from the School of Chemical and Life Sciences, reported the use of the Plan, Select, Monitor and Evaluate process spelt out in the SP SDL Framework (Figure 1) to explicitly teach and emphasise SDL and metacognition in their year 1 Laboratory and Process Skills module in the Diploma of Chemical Engineering. In the first session of the module, lecturers modelled the SDL process by verbalising the thought process in tackling given tasks through a series of “talk-aloud” questions. Students, in turn, made their thought processes of their learning experience explicit in a journal. This process was emphasised in all 10 activities in the module. The results of a survey of the students SDL competencies showed that students were able to model the behaviour of a self-directed learner by planning, referring to previously learnt knowledge, monitoring and evaluating their work,

and seeking help from friends when needed. The authors also reported that academically stronger students were more ready to take control of their learning as they struggled less to make sense of what they are learning, and therefore more confident to perform the learning tasks.

In this paper, the authors will share the efforts by Singapore Polytechnic (SP) to prepare our students to be self-directed learners. The paper will detail the study conducted in 2023 on the impact of flipped learning on students' SDL competences. The objective of the survey was to ascertain students' self-directed competencies in terms of their self-efficacy for learning and their use of different learning strategies. The findings will inform the institution on the support to provide to students. The paper will share the learnings gained from the study.

## **A PRELIMINARY SURVEY OF STUDENTS' SDL COMPETENCE**

### ***Objective***

In April 2022, Flipped Learning was instituted across all SP's programmes. By early 2023, all SP students would have at least one semester where lessons with lecture components were taught in the flipped learning modes. As a preliminary check on its impact on students' learning, a survey to study students' SDL competences was administered to all students at the end of the academic year in Feb 2023. The objective of the survey was to ascertain students' self-directed competencies in terms of their self-efficacy for learning and their use of different learning strategies.

### ***Methodology***

The survey adopted 20 questions from 2 components of the Motivated Strategies for Learning Questionnaire (Pintrich, 1991); the "Self-Efficacy for Learning & Performance" (SE) and "Metacognitive Self-Regulation" (MSR) scales. The MSLQ instrument was selected as it is a validated questionnaire whose scales could be used singly. In addition, given the concern of students' "survey fatigue", the number of items in each scale were reasonable. The survey was administered through a web-based survey application. Student participation in the survey was voluntary and anonymous.

### ***Findings***

1106 students or about 8.9% of the full-time diploma students in SP participated in the survey. Figure 2 shows the distribution of respondents by year of study.

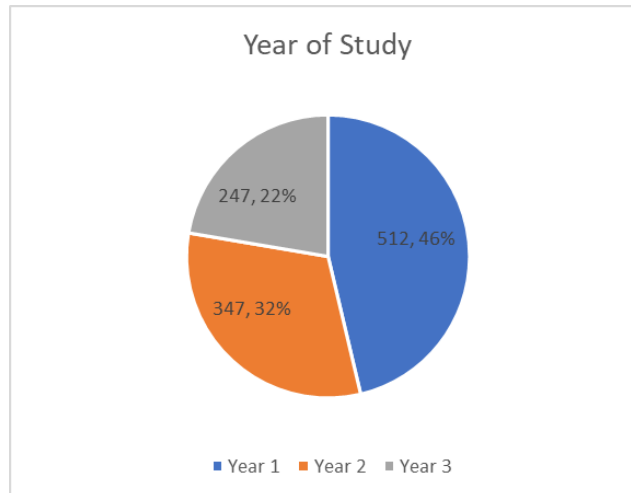


Figure 2. Distribution of 1106 respondents by year of study

Table 1 shows the findings for the Self-Efficacy for the Learning and Performance (SE) Scale. The mean scores of the SE scale ranged from 4.3 to 5.4 with an overall mean of 4.8 (SD = 1.5). The Cronbach alpha was 0.944 which showed an excellent internal consistency in the student responses. The table shows that about two-thirds of the respondents perceived themselves to be confident of learning the concepts taught in their flipped learning modules (68% reported somewhat true to very true, mean = 5.0, SD=1.5) and believed that they can receive an excellent grade (62% reported somewhat true to very true, mean= 4.8, SD = 1.6) for their flipped learning modules. In particular, 80% of the respondents perceived themselves as confident when it comes to learning the basic concepts taught in their flipped learning modules (80% reported somewhat true to very true, mean =5.4, SD=1.3).

Table 1. Results for Self-Efficacy for the Learning and Performance (SE) Scale

| Measure        | Questions                                                                                                                       | Scores (%) |          |           |           |           |           |           | Mean       | Std Dev    |
|----------------|---------------------------------------------------------------------------------------------------------------------------------|------------|----------|-----------|-----------|-----------|-----------|-----------|------------|------------|
|                |                                                                                                                                 | 1          | 2        | 3         | 4         | 5         | 6         | 7         |            |            |
| Ability        | I expect to do well in my flipped learning modules.                                                                             | 4          | 3        | 8         | 18        | 27        | 23        | 18        | 5.0        | 1.5        |
|                | I believe I can receive an excellent grade in my flipped learning modules.                                                      | 5          | 4        | 10        | 19        | 27        | 22        | 13        | 4.8        | 1.6        |
|                | Considering the difficulty of the modules, the lecturers, and my skills, I think I will do well in my flipped learning modules. | 5          | 4        | 9         | 22        | 30        | 20        | 11        | 4.7        | 1.5        |
| Confidence     | I'm confident I can learn the basic concepts taught in my flipped learning modules.                                             | 1          | 2        | 4         | 14        | 27        | 28        | 25        | 5.4        | 1.3        |
|                | I'm certain I can master the skills being taught in my flipped learning modules.                                                | 4          | 3        | 10        | 22        | 30        | 20        | 11        | 4.8        | 1.4        |
|                | I'm confident I can do an excellent job on the assignments and assessments in my flipped learning modules.                      | 4          | 4        | 9         | 23        | 29        | 21        | 11        | 4.7        | 1.5        |
|                | I'm confident I can understand the most complex material presented by the lecturers in my flipped learning modules.             | 7          | 7        | 13        | 21        | 26        | 17        | 8         | 4.3        | 1.6        |
|                | I'm certain I can understand the most difficult material presented in my flipped learning modules.                              | 8          | 7        | 14        | 22        | 26        | 14        | 8         | 4.3        | 1.6        |
| <b>Overall</b> |                                                                                                                                 | <b>5</b>   | <b>4</b> | <b>10</b> | <b>20</b> | <b>28</b> | <b>20</b> | <b>13</b> | <b>4.8</b> | <b>1.5</b> |

Cronbach's  $\alpha=0.944$  (Excellent Internal Consistency)

Table 2. Results for Metacognitive Self-Regulation (MSR) Scale

| Measure        | Questions                                                                                                                                                                 | Score band (%)                    |    |    |    |                           |    |    | Mean | Std Dev. |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|----|----|----|---------------------------|----|----|------|----------|
|                |                                                                                                                                                                           | Not at all true → somewhat untrue |    |    | N  | Somewhat true → Very true |    |    |      |          |
|                |                                                                                                                                                                           | 1                                 | 2  | 3  |    | 4                         | 5  | 6  |      |          |
| Planning       | Before I study new flipped learning module material thoroughly, I often skim it to see how it is organized.                                                               | 7                                 | 6  | 11 | 18 | 25                        | 16 | 18 | 4.7  | 1.7      |
|                | When I study for my flipped learning modules, I set goals for myself in order to direct my activities in each study period.                                               | 5                                 | 7  | 10 | 23 | 25                        | 15 | 15 | 4.6  | 1.6      |
|                | I try to think through a topic and decide what I am supposed to learn from it rather than just going through the materials when studying for my flipped learning modules. | 6                                 | 7  | 13 | 25 | 26                        | 13 | 10 | 4.4  | 1.6      |
|                | When studying for my flipped learning modules, I make up questions to help focus my learning.                                                                             | 8                                 | 11 | 17 | 23 | 21                        | 11 | 9  | 4.0  | 1.7      |
|                | When I become confused about something I'm studying for my flipped learning modules, I go back and try to figure it out.                                                  | 2                                 | 2  | 6  | 16 | 27                        | 24 | 24 | 5.3  | 1.4      |
| Monitoring     | When studying for my flipped learning modules, I try to determine which concepts I don't understand well.                                                                 | 1                                 | 1  | 6  | 17 | 32                        | 23 | 19 | 5.2  | 1.3      |
|                | I ask myself questions to make sure I understand the material I have been studying in my flipped learning modules.                                                        | 4                                 | 7  | 12 | 24 | 25                        | 15 | 14 | 4.6  | 1.6      |
|                | I often find that I have been studying for my flipped learning modules but don't know what it was all about. (R)                                                          | 11                                | 11 | 22 | 21 | 15                        | 13 | 7  | 3.8  | 1.7      |
| Regulating     | If I get confused taking notes in my flipped learning modules, I make sure I sort it out afterwards.                                                                      | 3                                 | 4  | 8  | 19 | 26                        | 20 | 19 | 5.0  | 1.5      |
|                | I try to change the way I study in order to fit my flipped learning module requirements and the lecturer's teaching style.                                                | 4                                 | 7  | 12 | 22 | 27                        | 16 | 12 | 4.6  | 1.5      |
|                | If my flipped learning module materials are difficult to understand, I change the way I study the material.                                                               | 4                                 | 6  | 12 | 24 | 26                        | 14 | 13 | 4.6  | 1.5      |
|                | When studying for my flipped learning modules, I often miss important points because I'm thinking of other things. (R)                                                    | 10                                | 12 | 19 | 18 | 17                        | 16 | 8  | 4.0  | 1.8      |
| <b>Overall</b> |                                                                                                                                                                           | 5                                 | 7  | 12 | 21 | 24                        | 16 | 14 | 4.6  | 1.6      |

Cronbach's  $\alpha=0.823$  (Good Internal Consistency)  
(R): Reverse question, responses are reversed

Table 2 shows the findings for the Metacognitive Self-Regulation Scale (MSR) scale. The mean scores of the MSR ranged from 3.8 (reversed question) to 5.4 with an overall mean of 4.6 (SD = 1.6). The Cronbach alpha was 0.823 which showed good internal consistency in the student responses. The table shows that slightly more than half of the student respondents perceived that they plan, monitor and regulate their learning activities when learning their flipped learning modules (54% reported somewhat true to very true). The students reported that they tended to monitor their learning by trying to figure out confusing material (75% reported somewhat true to very true, mean = 5.3, SD = 1.4), and material that they do not understand well (74% reported somewhat true to very true, mean = 5.2, SD = 1.3) and sorted out their notes if they get confused (65% reported somewhat true to very true, mean = 5.0, SD = 1.5).

Table 3 shows that the correlation of the 2 SE and MSR constructs ( $r = 0.58$ , significant at 5%  $\alpha$ ) was moderate. We can infer that students believe that they have the ability to do well in the flipped learning modules and are confident in their skills. This positivity influences them to carry out SDL activities that help them to plan, monitor and regulate their own learning.

Table 3. Correlation of the SE and MSR constructs

| Construct                                | Mean | Correlation                                 |
|------------------------------------------|------|---------------------------------------------|
| Self Efficacy for Learning & Performance | 4.8  | $r = 0.58^*$<br>(significant @5% $\alpha$ ) |
| Metacognitive Self-Regulation            | 4.6  |                                             |

\*One-tailed t-test conducted, p-value <0.05. Reject  $H_0$  of correlation  $\leq 0$

## CONCLUSION AND MOVING FORWARD

The institutional adoption of flipped learning for modules with lecture components in 2022 required students to be self-directed and take ownership of their learning. In a survey conducted in February 2023, the students perceived themselves as confident of learning concepts taught in their flipped learning modules and believed that they have the ability to do well. They adopted strategies like self-assessment and questioning that helped them monitor how well they understood the material. As flipped learning is the major institution-wide pedagogy implemented in recent years, the findings from the study indicated that it did not have any adverse impact on students' motivation and strategies for learning and could have contributed to the development of these competencies.

The findings of the study, however, have limitations as there was only one survey conducted. 1106 or 8.9% of the student population responded to the survey. While the data provided the institution with a preliminary indication of the students' SDL competences, it may not be representative of the student population. More data is needed. More insights could be drawn if there were pre-test or previous years' data available for comparison. The flipped learning pedagogy implementation across the modules ranged from 5 years to one semester. Also, in some modules, the SDL skills was explicitly taught and scaffolded while in others, students' SDL experiences were not scaffolded. This inconsistent implementation may have also impacted the lecturers' experience and expertise in implementing SDL activities and hence, students' experiences and development. The study was also limited to 2 dimensions: 'Self-Efficacy for Learning' and Metacognitive Self-Regulation. Other dimensions of SDL like intrinsic motivation, personal responsibility, and growth mindsets were not included in the study. There were also no qualitative data from interviews or student reflections in this study to



provide deeper insight and anecdotal evidence, hence limiting the conclusions that can be drawn.

Moving forward, a detailed mixed methods research study will be carried out in 2024 to further investigate the impact of the institution-wide implementation of flipped learning pedagogy involving surveys and in-depth interviews with students on their self-directed learning activities as well as interviews with lecturers on their teaching and learning approaches to support students during flipped learning.

## **ACKNOWLEDGEMENT**

The authors would like to thank colleagues from the School of Math and Science for their invaluable assistance with this study.

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# ACTIVE LEARNING IN CIVIL ENGINEERING: SOIL-MECHANICS AND STEELWORK DESIGN AS CASE STUDIES

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## ABSTRACT

The increasing and rapid technological evolution of digital technology has promoted the embrace of digitalization in the academic teaching of civil engineering. In recent years, new digital technologies have emerged as a real efficiency multiplier for the sector. It's obvious that if we don't adjust our academic syllabus in accordance with this global trend, it will remain obsolete. To circumvent the aforementioned issue, the civil engineering department at Esprit has keenly introduced technologically inclined courses into its academic curriculum by implementing the aspect of digitalization into its engineering program, such as the Soil Mechanics and Design of Steel Framework courses. These courses are taught to third-year engineering students at the ESPRIT School of Engineers. Moreover, to ensure a high level of learning outcomes, several active learning methodologies were adopted (i.e. Flipped Classroom, Project-Based Learning, Peer-to -Peer). The use of previous methods sets students in a better environment in which they can learn efficiently from practicing, develop most in-demand soft skills (such as critical thinking, teamwork, problem solving, time management, creativity, etc.), unleash productivity, and foster innovation and originality. Through this paper, we explain the chosen approaches with extensive details according to the main CDIO standards (like standard 5: Design-Implement Experiences and standard 8: Active Learning), where students are led to gradually use skills acquired during these courses. Such an approach would allow them to acquire advanced design skills while applying their digitization's abilities, for instance, to laboratory soil testing and the development of automated programs to calculate steel framework elements. Finally, we present the main benefits and drawbacks as feedback from applying these new approaches. Nevertheless, we have noticed that when the project consists of solving real-world problems, the commitment and motivation of students considerably increase. Furthermore, this experience provides a rich learning environment and a challenging endeavor.

## KEYWORDS

Digitalization of education, Active learning, Soft and engineering skills, Civil engineering, Standards: 5, 8

## INTRODUCTION

Digital technology is increasingly invading the engineering profession, and its integration seems almost mandatory in all sectors (Nash, S. et al., 2012). This integration is an obvious result of adapting to the changing needs of society and the market, especially after the COVID-19 pandemic, which forced all sectors to follow this global trend to survive on the market and ensure their share of competitiveness (García-Alberti, M. et al., 2021). The same applies to the construction and civil engineering sectors, which are making great strides towards the integration of digital technology, with an average annual growth rate of 16% by 2025, according to a study by Roland Berger (2023). This estimated strong growth is due to the advantages of digitizing civil engineering, with gains that can be estimated at \$1.6 trillion per year worldwide. According to a McKinsey study made by Koeleman, J. et al. (2019), the gains from digitalization are derived from the benefits of integrating digital technologies, such as customization of projects, reduction of costs and deadlines, improvement of quality and safety, sustainability and environmental responsibility, etc. And to succeed in this challenge of digital transformation, the civil engineer as well as one of the actors must also align digitalization through the acquisition of new skills that adapt the most commonly used digital technologies, such as BIM, IOT, etc. The training of civil engineers plays a key role in the acquisition and development of digital skills for the future, which must be based on the adaptation of content and methods of educational tools to digital technologies. This is why the civil engineering department has begun to integrate these new technologies into the training of engineers. This paper develops our experience with 3-year engineering cycle students in the reform of both foundation and support modules and steel framing. In the first two sections, let us detail our framework for the two modules. The third section will deal with the limits, and we will end with a conclusion.

## METHODOLOGY

The way we teach is continuously changing. With the emergence of new teaching approaches, we are witnessing a paradigm shift from classic to active learning (Asok, D. et al., 2019). We sometimes call it the facilitation of learning. With the development of technology, students find themselves in front of an abundance of information available almost instantaneously. They don't need the physical companionship of the teacher to advance in their learning, at least from those who are autonomous. Hence, educators must play a different role than the traditional one, where they act as facilitators and teach students how to learn effectively, discover, and filter relevant information rather than being transmitters of information.

The literature describes a variety of educational research approaches, including experimental, survey, and action strategies. The effectiveness and quality of their results vary depending on the phenomenon under investigation or the problem being treated. The choice of methodology is critical since it drives the study plan and defines data gathering and analysis scheme. The current study primarily used the action research methodology, which was deemed more appropriate and efficient for achieving our overall goal of improving the educational technique currently used at ESPRIT, School of Engineering, through promoting self-directed learning, autonomy, and project design skills among engineering apprentices. Action research typically seeks to improve the current situation rather than to generate generalizable theoretical knowledge. As a result, such strategies commonly lack extensive documentation and formal reporting. In this paper, the action research strategy was based on four pillars: a. literature studies and results from similar projects, b. instructor observations based on their prior experience teaching the concerned courses, c. our personal involvement in improving the

courses concerned by the current study at the ESPRIT's civil engineering department, and d. feedback from students who have participated in the courses under study.

As expected, a relevant similarity has been perceived between the observations reported in the literature (Chia Chew Lin et al., 2020) and those revealed by the instructors of the courses. According to teaching staff observations, a large percentage of students consistently show a strong inclination to ask their lecturers to give them direct answers on a one-on-one basis, demand instructors correct their mistakes, or display anxiety and resistance to develop their numerical and experimental tools to tackle the theoretical problem or invent or improve an approach or apparatus to measure physical parameters by using technological, coding, or designing skills. While the teaching staff has to guide them with considerable effort. Implying that quite a number of the students are not ready or simply reluctant to take ownership of their learning or challenge themselves to acquire new skills beyond their field of expertise. Still, it was also observed that some students are very driven, self-directed, enthusiastic about experimenting, and self-learning new abilities. By referring to Gibbon's Spectrum of Self-Directed Learning depicted in Figure 1., our students can be identified at different levels, with quite a handful of them falling into the self-directed learning phases while the majority of them have exhibited behaviors that indicate low ownership or considered as incidental self-directed learner as per the definition of Gibbon (2022).

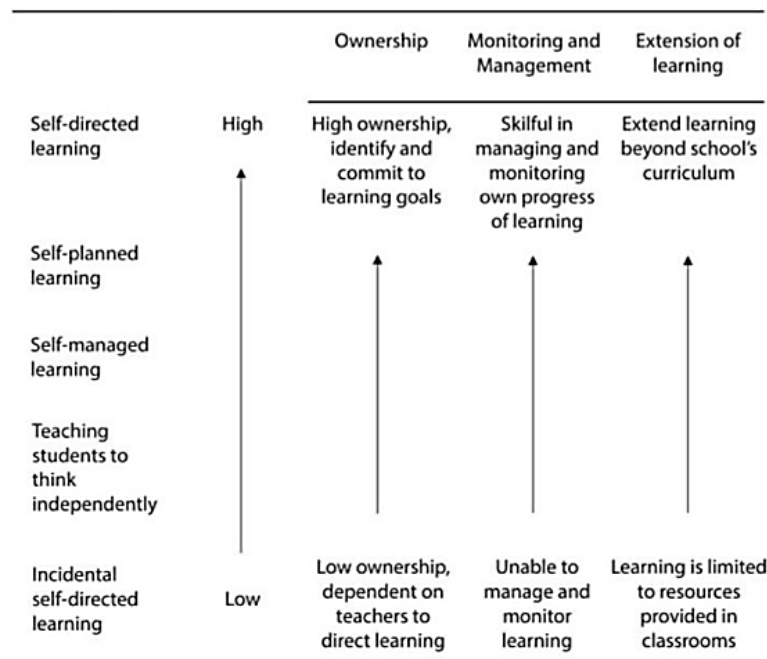


Figure 1. Gibbons Spectrum of Self-Directed Learning

To achieve this study objectives, a feedforward method has been adopted where interventions have been implemented in both courses to encourage students to become self-directed learner while acquiring new coding, design and research skills. Changes carried out for the courses are explained with further details in subsequent sections of this paper. At the end of the courses, surveys to evaluate the new versions of courses with recommended changes have been distributed to students. Hence, results of the surveys have been analyzed in order to confirm success of the experiment and interpret a further change that may improve other aspects of the courses that were not improved by the modifications adopted during the current version of the courses.

## **Design of steel framework course**

In this context, and as a traditional continuous improvement adopted by the civil engineering department, I decided, two years ago, to switch the pedagogical way of teaching the “steel framework design” course from an almost classic paradigm to a multi-active approach to learning where students are considered the central part of the teaching process. The course of “steel framework design” forms part of the civil engineering undergraduate program and is one of three modules offered in steel design. It is a lecture-based course and consists of a series of eight chapters. Students learn about the fundamentals of designing steel elements (like beams and columns, etc.). The design and calculations of real elements (such as portals, beam columns, purlins, paddings, connections, etc.) are covered in the second semester simultaneously with the laboratory software. In order to achieve all the desired learning outcomes, students must not only possess strong prerequisites but also develop the most in-demand engineering and soft skills. In a nutshell, let us define the scope of the arrangement and the material of the course. It is comprised of eight chapters, organized as shown below in Table 1.

Table 1. Content of the 42-hour “Design of Steel Framework” course

| <b>Chapter #</b> | <b>Name</b>                                                                                     | <b>Duration</b> |
|------------------|-------------------------------------------------------------------------------------------------|-----------------|
| 1                | History, Introduction, fields of application and terminology of steel construction              | 4 hours         |
| 2                | Basis design of steel construction design according to Eurocodes                                | 2 hours         |
| 3                | Calculation of climatic loads (wind and snow) on constructions                                  | 6 hours         |
| 4                | The essence of the resistance design of steel members without consideration of buckling effects | 10:30 hours     |
| 5                | Justification of compressed elements considering buckling effects                               | 4 hours         |
| 6                | Justification of bent elements with respect to lateral torsional buckling                       | 6 hours         |
| 7                | Justification of elements with respect to local buckling                                        | 3:30 hours      |
| 8                | Design of composite slabs and Beams                                                             | 6 hours         |

Besides, these are the principal learning outcomes of the module:

- recognize structural steel fabrication processes;
- memorize the terminology of a hall-type steel structure;
- calculate the wind action on a quadrangular steel construction;
- justify the metal parts regarding the stresses applied, considering the phenomena related to shape instability (buckling);
- use and apply standards for the design of structural steel and composite elements.

In the traditional way, the instructor first exposes the principals and concepts covered by the course using a data show and whiteboard, followed by a resolution of a series of exercises. Usually, some students apply. They participate, share their ideas, ask questions, do calculations, and take notes, while the majority is inactive, and in the best case, those students are limited to just following up on the correction. The rhythm is so tensioned and stressful. Therefore, the post-exams evaluation shows a very weak rate of learning outcomes and is

almost inefficient and unacceptable. In its newest form, students are organized into groups of three individuals. Then, the content of the course is assigned to each group, and the material pertaining to every chapter is allocated to each member of the group. Here, we recall the flipped or inverted classroom, team-based learning, and peer-to-peer learning methodologies. Figure 2 illustrates the arrangement of groups in a typical classroom, the relationships between members of each group, and the eventual relationships among every group and other groups (showed in red arrows). We can see that the acquisition of related learning outcomes is constructed not only by personal effort but is substantially based on interactions between all members of a group and even with other members of other groups. This involves students working together in a personalized learning environment and supporting each other in the learning process without the need for direct and recurrent teacher's support. They feel more involved, applied and motivated in the teaching process.

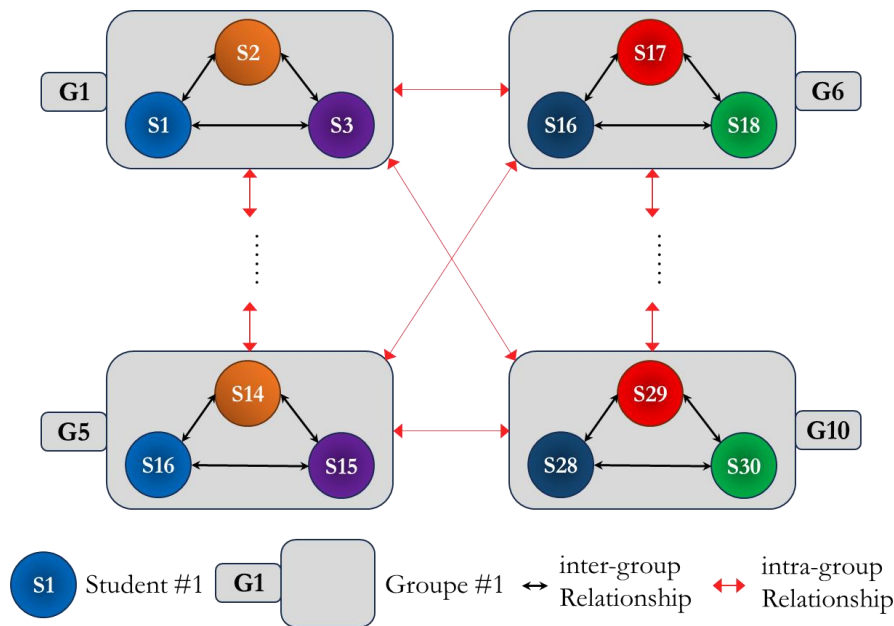


Figure 2. Illustration of the arrangement of groups in the classroom

At the beginning of each chapter, the instructor provides and exposes the principal concepts of the course. Then, each learner has to read and understand it attentively at home and in person, consult related parts of the Eurocode, try to induct a recap, and then implement the different exercises on MS Excel spreadsheets. To do so, students have to toggle between course material, some books, MS Excel tutorials, online resources, and last but not least, Eurocodes. It is important to be patient, autonomous, and careful to grasp only relevant information in order to create links between ideas, understand the concepts in depth, and learn how to be more effective and concise in filtering only the necessary information from available data. The instructor, as mentioned above, plays the role of a tutor or coach that facilitates and encourages conversations and teamwork collaboration. He also guides them towards the right choices without disclosing explicitly the solution as it was in the traditional way. Once the work is done, so that each student in all groups has effectively accomplished his part of the work, he should then explain what he has learned and accomplished to his groupmates, since for each chapter, every student has almost one-third of the content. As a practical example, we take the fourth chapter that deals with resistance design. But before starting calculations, some preparations must be made. Hence, in the first part, the first student is charged to learn about section class principles and how to determine the type of analysis according to Eurocode3. The second student is engaged in calculating section geometrical and mechanical



characteristics, and the third one is expected to conduct a Von Mises section assessment. Those concepts are essential to conducting resistance design, which is covered in the second part of the chapter.

### **Soil mechanics rocks course**

mechanics plays a crucial role in the training of engineering students as it provides them with both theoretical and practical knowledge to design, construct, and control various geotechnical structures such as foundations, retaining walls, dams, tunnels, embankments, and dikes. It can also be used to predict the behavior of soils under the effects of geotechnical loads. In the civil engineering department, soil mechanics is spread over two semesters. In the first semester, students follow a theoretical module in soil mechanics and do practical work in the soil mechanics laboratory. In the second semester, students follow another theoretical module called foundation and support and another module in the form of a project called "BE Foundation System," which aims to design and calculate underground and surface structures. Recently, a reform has been carried out over the last two years on the foundation and support modules, with an hourly load of 42 hours. The reform essentially concerns the integration of a part in the course called TP-Design of Geotechnical Characterization Tools in the form of an APP where the student is called to: a. Study and design test apparatus and b. develop digital tools (e.g., programming or coding). In summary, the implementation of this reform will provide students with valuable digital knowledge and practical skills in geotechnical engineering, ultimately enhancing their future career prospects.

#### *Project selection*

At the beginning of the semester, the project is launched to the student, detailing the pedagogical objective and the outcomes of the module already mentioned. The start-up always begins with the presentation of the problem, which has been the improvement of the existing geotechnical test strips in the Soil Mechanics Laboratory or the design and implementation of new tests that can be useful by integrating the numerical parameter.

Table 2. List of Soil Mechanics Projects

| # | Title of the project                                         | # Groups |
|---|--------------------------------------------------------------|----------|
| 1 | Variable and constant load permeameter with measuring sensor | 2 groups |
| 2 | oedometer test                                               | 1 group  |
| 3 | Permeability-meter and soil moisture sensor                  | 1 group  |
| 4 | Casagrande Test Modeling                                     | 1 group  |

The choice of project is based on a bibliographic study and the students' feedback on the "Soil Mechanics Practical Course", and this is done with a view that aims to boost their creativity and involve them in the learning process by developing their critical sense and their skills in bibliographic research and group work. After two weeks of desk research and testing the needs of the soil mechanics laboratory, each group presented their project idea in front of their classmates, and a working session was scheduled to discuss and validate the project idea. Table 2 illustrates the projects proposed and implemented by the students.

## *Results and implications*

The ever-moving reality in the world implied a major change to the engineer profile. Hence, proper education, which means equipping the engineering students with proper technical and interpersonal skills, raises as a necessity, allowing them to lead the changes required worldwide. Limiting the apprentices of engineering to technical skills, such as repetitive calculations and deploying empirical correlations, is deemed insufficient to meet the needs of their projects. Engineers need to develop their own tools for simulation and build their own experimental setups that satisfy the requirements of their projects or innovative ideas. Innovation requires thinking outside the box and eventually using different tools besides those that are available.

In accordance with the aforementioned objectives, the engineering apprentices in their third year of civil engineering have been challenged with real-world problems related to geotechnical fields. Most of the equipment that is in the school laboratory is still classic, fully relying on the human being, involving several repetitive and time-consuming tasks. Permeability measurements and oedometer testing are among the most common techniques that are required by civil engineering projects and have hence been selected from the list of projects presented in Table 2. The students were required to optimize the previous tests by automating the process involved. Three teams were established to conduct the project: the first team is responsible for the numerical modeling of the permeability meter, the second team is responsible for conducting electronics wiring and data acquisition systems, and the third team is responsible for building the equipment (Figure 3). The objective was to establish equipment that allows the automatic measurement of a soil sample during transient and continuous flow regimes. Thus, the Darcy equation was reached by implementing the differential pressures and flow rates that are continuously determined using the sensors installed on the permeability-meter equipment. Consistent communication between the three teams has been established throughout the project period in order to ensure a fluid exchange of information between them. The project was considered challenging at several levels, as inferring learning unconventional skills for a civil engineering apprentice: computer-assisted design (CAD), electronics wiring and programming, and constructing a full-edged electrometrical system that was tailored in accordance with the specific needs of the school laboratory, in addition to enhancing interpersonal skills like technical reporting, professional communications, leadership, and teamwork capabilities.

For the oedometer, the classic approach requires a manual measurement at a specific time frame that can range up to hours and even days. To overcome previous time restrictions and reduce the human error involved during the recording of measurement processes, the team members have designed an electronic data acquisition system allowing a systematic recording of the subsidence during the evolution of the oedometer tests. The experimental data acquired is hence interpreted, and soil parameters are inferred automatically by the software programmed by the students (Figure 4). The previous learning-through-project approach has promoted the professional and interpersonal skills of apprentices in the civil engineering departments, allowing them to acquire transferable acquaintances and capabilities that can apply to real projects during their professional careers afterward. The challenging realities of the engineering world today indicate that graduate engineers go beyond and beyond classic knowledge to extend covering, programming, design, and custom to find solutions to the “not-regular” problems that they may face during their career.

The results of surveys, Figure 5; depicted a high satisfaction by the students in regards to the new learning approaches adopted for the course. The strategy to use less direct instruction to promote active learning in the classroom was a helpful and well appreciated by the apprentices

so it will remain for the next year. Still, learning coding, technological (electronics programming and installation), and practical research skills represented a major challenge to the students who felt overwhelmed by the extent of knowledge and prerequisite that need to be acquire in a short period. To deal with the previous issues; learning strategies, including teaching the students the right mindset to conduct research work; as well as organizing short training sessions in coding and electronics programming, have to be planned for the next academic year.

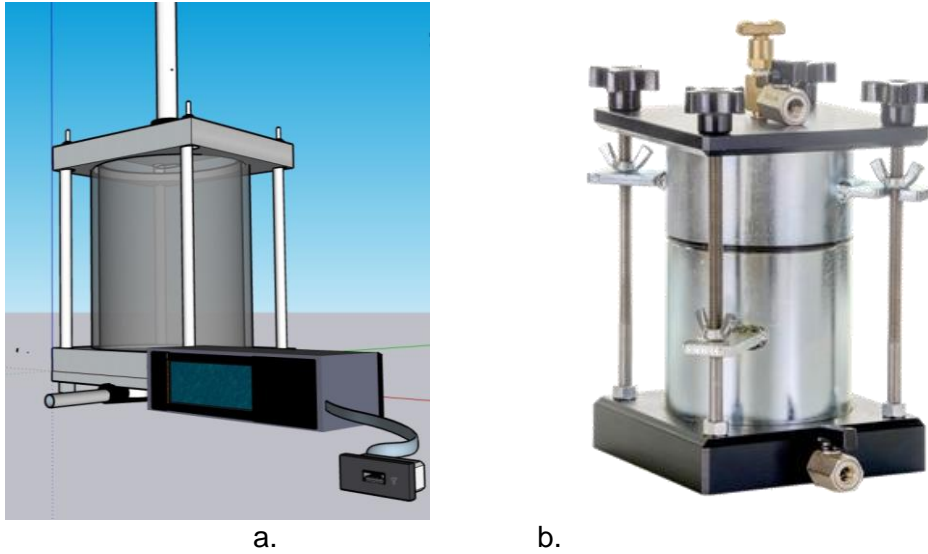


Figure 3. Permeability-meter: a. CAD and b. Prototype

```

# -*- coding: utf-8 -*-
"""
Spyder Editor

This is a temporary script file.
"""

import serial
import matplotlib.pyplot as plt

# Configure the serial port
-ser = serial.Serial('COM3', 9600)

# Set up the plot
plt.ion()
fig, ax = plt.subplots()
line, = ax.plot([], [])

# Initialize the data arrays
x_data = []
y_data = []

# Start the plot loop
while True:
    # Read a line of data from the serial port
    data = ser.readline().decode().split(",")

    print(data)

    # Convert the data to a float and append it
    to the arrays
    try:
        time = float(data[0])
        value = float(data[1])
        x_data.append(time)
        y_data.append(value)
        print(time)
        print(value)
    except:
        print("error")

    # Update the plot
    line.set_xdata(x_data)
    line.set_ydata(y_data)
    ax.relim()
    ax.autoscale_view()
    fig.canvas.draw()
    fig.canvas.flush_events()

```

Figure 4. Oedeometer: data logging code snippet

## CONCLUSION

In recent years, companies have tended to adopt a skill-based hiring approach based on candidates' holistic set of skills and not just their educational qualifications. Thus, we can say that these emerging methodologies contributed to responding to this need and helped to create a friendly atmosphere and suitable environment where students could develop and foster their skills and learn at their own pace instead of staying passive and wasting time. Furthermore, this allowed students to:

- be more autonomous and self-confident,
- share their thoughts and perspectives and exchange ideas.
- recognize the utility of active learning and be cautious about the necessity of digitalization.
- learn in a personalized and more flexible learning environment.
- collaborate and resolve conflicts and disagreements;
- feel more involved, applied and motivated in the teaching process;
- develop personal skills, etc.

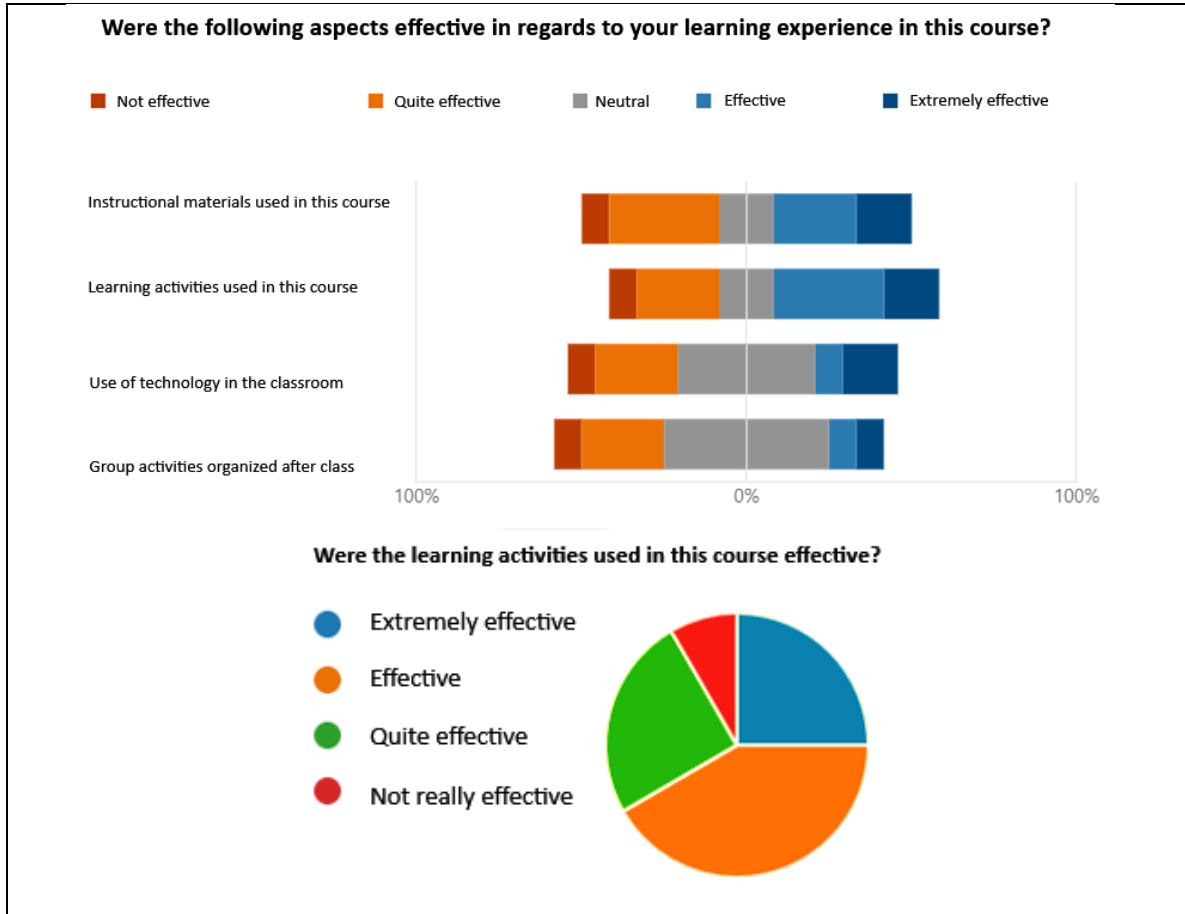


Figure 5. Surveys results

Moreover, digitalization enables engineering education to be more innovative, collaborative, and efficient. It contributes to enhancing the quality of education and accessibility to curricula. Future engineers, by automating tasks using software tools, will:

- perceive things differently and from wider perspectives;
- develop high-demand 5 C's competencies: collaboration, communication, critical thinking, creativity, and choice;
- save time and become more efficient in problem solving;
- improve problem-solving and time-management skills;
- became more capable of handling advanced and more complex problems.

However, the results of some methodologies remain controversial as students may differ on their level of understanding and be inclined to use other students' thoughts and reproduce them in their own assignments (Zhang, A., 2012). Generally, the method of using less direct instruction to foster active learning and promote designing capabilities was effective and well recognized by both the instructors and the students. However, acquiring advanced coding and technological skills presented a significant obstacle for the students. Therefore, it is recommended to organize short coding and electronics programming training sessions prior to or at the start of the courses. Finally, we hope that this work will inspire our colleagues to start considering the learning approaches investigated and implemented in this study for their own courses as promising impacts are highly anticipated based on results obtained in this paper.

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# **SUSTAINABILITY IN CIVIL ENGINEERING EDUCATION**

**Taheni KALLEL, Safa MHADHBI, Meriem SOUBGUI**

ESPRIT, School of Engineering

## **ABSTRACT**

Introducing sustainable development in the academic curriculum of engineers is a necessity related to international objectives. Civil engineering, one of the sectors which uses natural resources and energy, must contribute to search for innovative solutions to reduce the environmental impact of its projects. In addition, the optional standard for engineering education named sustainable development, is attached as an essential competence in the CDIO framework. This paper focuses on the integration of the sustainable development aspect into the civil engineering training at ESPRIT for every level of learning. It first presents the process of integrating sustainable development into the civil engineering curriculum based on CDIO standards. Secondly, we will detail pedagogical approaches and learning tasks used in courses. Finally, we conclude with recommendations and outlooks. This study, which is related to civil engineering education has firstly an important pedagogical impact thanks to the application of the 17 Sustainable development goals built by the United Nations in 2015 to make them a reality. Second, it presents a strong impact on society which is known through the return of professionals and their needs within the framework.

## **KEYWORDS**

Sustainability, Civil engineering, Curriculum, learning tasks, Standards: 1, 2, 5, 6, 8

## INTRODUCTION AND BACKGROUND

Engineering is a profession focused on resource consumption and continuous development. In civil engineering, natural resources are excessively used, and high greenhouse gas emissions are released into nature (Junar E, 2022). Climate warming is one of the consequences of this phenomenon. So, the search for environmental and societal solutions is a duty of civil engineers.

In accordance with the CDIO standards (Malmqvist et al., 2020 a&b, 2022), sustainable development can be introduced in the education program.

Students in civil engineering participate in the challenge of sustainable development with the purpose of green solution for building to protect planet and give good life conditions. They play a pivotal role in the transition towards a sustainable society.

The first part of this paper will be dedicated to explain how sustainable development is introduced in the training program based on CDIO standards, the teaching methods used will be described. Finally, the main results will be discussed for further recommendations.

## PROGRAM PHILOSOPHY

The academic education in civil engineering, at Esprit (School of Engineering), takes five years when pedagogic engineering is adopted. This method is based on the detection of generic skills collected after investigations of professionals which is carried out every five years to reform the curriculum in line with the needs of professionals.

Teams are working on investigations to prepare a survey and they contact professionals to see with them the most competences searched on the civil engineering. In this survey we collect also the recommendations of professionals for continuous improvement in both the short and long terms. Therefore, both quantitative and qualitative analyses give rise to the generic competency repository (Ajailia N et al., 2019) (Figure 1).

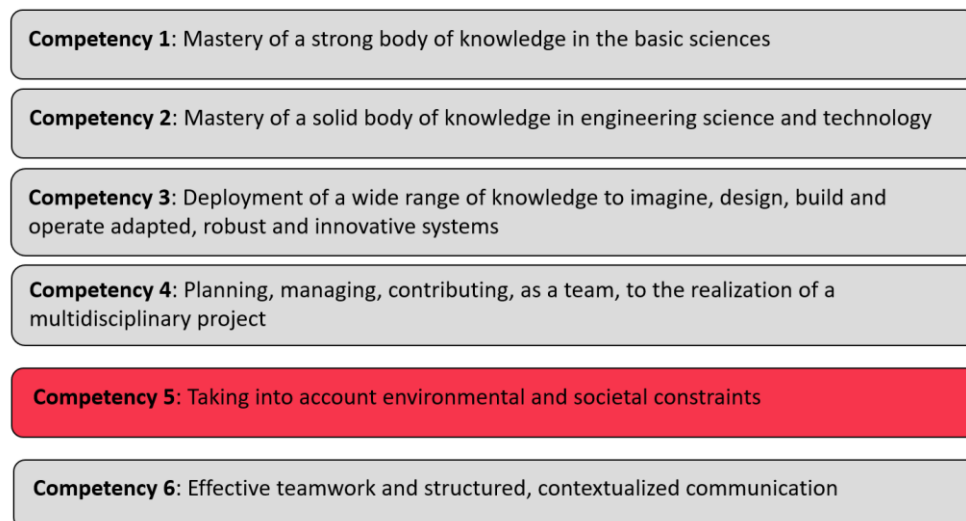


Figure1. Generic competency repository



The consideration of environmental and societal constraints is summarized on the fifth competency of civil engineers at ESPRIT. This generic competency is detailed in specific skills which subsequently give rise to the learning outcomes. This latter is thereafter divided into teaching units which are distributed on the different education levels.

In the engineering curricula, the sustainable development goals are incorporated for the development of future engineering education and help them to think about the environment and social issues (Gumaelius & Kolmos, 2020). So, module sheets are prepared when much information, such as learning outcomes module content and evaluation process, are summarized. All modules are affected to a responsible to follow permanent and temporary teachers and to make sure that the module content is respected. Teamwork and meetings can take place to answer questions or provide recommendations for teachers.

After each teaching module, students realize a lessons' assessment. They fill out a form online and the results are confidential. Teachers sensitize students to assist at this evaluation to have sufficient responses. The return of these evaluations is examined to improve the quality of teaching for the next years and students will be informed to complete the circle.

## **CURRICULUM IMPLEMENTATION**

Specific skills which have emerged from the generic competence "Taking into account environmental and societal constraints" are (Ajailia N et al., 2019):

- Act as a responsible professional
- Be open and act ethically
- Self-assess your own work
- Position the company's actions in relation to environmental issues
- Position the company's actions in relation to social issues
- Apply occupational safety and health standards

These skills have been described as learning outcomes that have been combined to form teaching units. The integration of those units across civil engineering curriculum is presented in Figure 2 for integrated preparatory and Figure 3 for Engineering training.

| S1                                                   | S2                                                  | S3                                                  | S4                                                  |
|------------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------|
| LU Basic Mathematics 1                               | LU Basic Mathematics 2                              | LU Basic Mathematics 3                              | LU Basic Mathematics 4                              |
| LU initiation to documentary research                | <i>LU Computational Mechanics</i>                   | LU Materials                                        | LU Measurements and Topography                      |
| <i>LU Urban Planning and Sustainable Development</i> | <i>LU Introduction to Civil Engineering</i>         | LU construction processes                           | <i>LU Associative &amp; Collaborative Project</i>   |
| LU Physics Chemistry                                 | <i>LU Communication, Culture and Citizenship A1</i> | LU Mechanical                                       | LU Applied Physics                                  |
| LU Communication, Culture and Citizenship F1         |                                                     | <i>LU Communication, Culture and Citizenship A2</i> | <i>LU Communication, Culture and Citizenship F2</i> |
|                                                      |                                                     | <b>LU Internship 1</b>                              |                                                     |

Figure 2. The training plan for Integrated preparatory

| S5                                                  | S6                                                  | S7                                                  | S8                                                  | S9                                                              |
|-----------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------------------|
| <i>LU Applied Mathematics</i>                       | <i>LU Data analysis</i>                             | <i>LU Digital Resolution Methods</i>                | <i>LU Hydraulic</i>                                 | <i>LU pathology and working conditions in Civil Engineering</i> |
| LU Applied Mathematics                              | LU Foundations & Supports                           | <i>LU Prestressed Concrete</i>                      | <i>LU Project management and management</i>         | <i>LU New Technologies and Optimization</i>                     |
| LU Theory of Structures                             | LU Calculation and design of structures             | <i>LU engineering works</i>                         | <i>LU Optional</i>                                  | <i>LU Optional (project)</i>                                    |
| LU Construction Technology                          | LU Management of the company                        | <i>LU Road &amp; Hydrology</i>                      | <i>LU Project Structures &amp; Structures</i>       | <i>LU Law and regulations</i>                                   |
| LU Homogenization                                   | <i>LU Communication, Culture and Citizenship F3</i> | <b>LU Internship 2</b>                              | <i>LU Communication, Culture and Citizenship F4</i> | <i>LU Preparation for working life</i>                          |
| <i>LU Communication, Culture and Citizenship A3</i> | <i>LU Building Structures Project</i>               | <i>LU Communication, Culture and Citizenship A4</i> |                                                     | <b>LU Internship 3</b>                                          |

Figure 3. The training plan for Engineering training.

As seen in figure 2, the urban planning and development project is the first module introducing sustainable development in academic education of civil engineering. when students conceive the architecture of a space following the recommendations of high environmental quality. These aspects are generalized within the framework of the "Introduction to civil engineering" in which the students have the occasion to recognize the ecological structures.

In the second level, In the sustainable construction project and environment module students make models with ecological materials after studying the carbon footprint of standard building materials and compare them with ecological ones. The architectural aspect and sustainability approaches are the prerequisites of this unit taken from the first level of education. The students also prepare a good practice guide to justify the materials selected in their models. For the evaluation of this work, the coach evaluates the work progress during course sessions and finally, the method of pairs evaluation is used to engage students.

In the third level of education, the SDGs are taught to students who have completed the first cycle of training. The introduction to the SDGs was part of the homogenization module and aims to discover the framework of the goals set by the United Nations towards the end of 2030. The pedagogy adopted during this module was the project-based approach and the students were able to discover all the SDGs. The engineering student at this level has learned how to position himself in relation to what he has studied in terms of sustainable development and how he can apply the SDGs in the next modules as well as their contributions in engineering.

At the achievement of the third level, students select an option unit between four which is studied on the fourth and the fifth level of education. In table 1, the different modules of each option unit and hourly load of each one are presented.

Table 1. Modules of the different option unit

| Teaching Unit                           |                                                 | Semester 8 [19-20] | Load                                           |          | ECTS     |           |     |
|-----------------------------------------|-------------------------------------------------|--------------------|------------------------------------------------|----------|----------|-----------|-----|
|                                         |                                                 |                    | Hours                                          | Taught   |          |           |     |
| Hydraulics                              | General Hydraulics                              | 72                 | 15                                             | 1        | 1        | 6         |     |
|                                         | Urban Hydraulics (Field Visit)                  |                    | 42                                             | 1        | 3        |           |     |
|                                         | <b>Roads and Miscellaneous Networks Project</b> |                    | 15                                             | 2        | 2        |           |     |
| Project management and management       | Construction Project Management (Site Visit)    | 81                 | 30                                             | 1        | 3        | 7         |     |
|                                         | Intellectual Property Law                       |                    | 9                                              | 2        | 1        |           |     |
|                                         | Innovation & Entrepreneurship                   |                    | 42                                             | 1        | 3        |           |     |
| Optional Teaching Unit                  | Structure                                       | 114                | 42                                             | 1        | 3,5      | 10        |     |
|                                         |                                                 |                    | Stability of Buildings                         | 30       | 1        |           | 3   |
|                                         |                                                 |                    | Soils & Structures                             | 42       | 1        |           | 3,5 |
|                                         | Roads and bridges                               |                    | Roads and interchanges                         | 42       | 1        |           | 4   |
|                                         |                                                 |                    | Bridges & Tunnels                              | 42       | 1        |           | 4   |
|                                         |                                                 |                    | Pathology and maintenance of roads and bridges | 30       | 1        |           | 2   |
|                                         | Eco-building and energy efficiency              |                    | Thermal regulation of buildings                | 42       | 1        |           | 4   |
|                                         |                                                 |                    | Aeraulic installation of buildings             | 30       | 1        |           | 2   |
|                                         |                                                 |                    | Eco-construction                               | 42       | 1        |           | 4   |
|                                         | Oil & Gaz                                       |                    | Reservoir Engineering                          | 42       | 1        |           | 4   |
|                                         |                                                 |                    | Drilling Engineering                           | 42       | 1        |           | 4   |
|                                         |                                                 |                    | Production Engineering                         | 30       | 1        |           | 2   |
| <b>Projet Structures &amp; Ouvrages</b> |                                                 | <b>39</b>          | <b>39</b>                                      | <b>1</b> | <b>4</b> | <b>4</b>  |     |
| Communication, Culture and Citizenship  |                                                 | 42                 | 42                                             | 1        | 3        | 3         |     |
|                                         |                                                 |                    | <b>348</b>                                     |          |          |           |     |
|                                         |                                                 |                    | <b>24,9</b>                                    |          |          | <b>30</b> |     |

Among others, oil and gas option unit and Energy efficiency and Eco-building unit are prepared for civil engineering programs. These options'units contain three modules each one on the fourth level of education and one project for the fifth one.

In the oil and gas course, students study three optional modules (reservoir, drilling and production engineering). This unit is the basic production engineering course for civil engineering students who aim to initiate a career as a production engineer or assist on oil and

gas development projects. This course gives adequate competence to perform production facilities design and conduct production optimization.

The purpose of the energy efficiency is establishing an energy audit of the existing building and proposing solutions for improving the energy efficiency of housing or optimizing the design of new buildings. The Eco-building part treats the alternative materials of civil engineering, bio architectural design and the good practices of using natural research (energy and water).

For the first experience, the teaching method is based on the sharing of information with students, and they use the course for establishing a model which respects all setpoints.

In the last semester, students applied their sustainable development prerequisites to design and implement professional projects.

After the first experience of training with these options units, students see that full theoretical information is presented for the energy efficiency and Eco-building option and they didn't appreciate the evaluation method (model production). And for the oil and gaz option unit, they see that many mathematical equations can affect the student concentration.

The student's return is very well appreciated by a responsible. Teamwork takes place in searching for an effective solution. The idea is to combine the two options on only one named natural resources and energy efficiency (RN2E). This option unit contains different modules (table 2). Students work on the production of numeric models for the Eco-building module and digital simulation for the others.

Table 2. RN2E option unit on plan of education

| Teaching Unit                                   |                                                 | Semester 8 [22-23]                             | Load         |   | ECTS |           |
|-------------------------------------------------|-------------------------------------------------|------------------------------------------------|--------------|---|------|-----------|
|                                                 |                                                 |                                                | Hours Taught |   |      |           |
| Hydraulics                                      | General Hydraulics                              | 72                                             | 15           | 1 | 1    | 5         |
|                                                 | Urban Hydraulics (Field Visit)                  |                                                | 42           | 1 | 3    |           |
|                                                 | <b>Roads and Miscellaneous Networks Project</b> |                                                | 15           | 2 | 1    |           |
| Construction processes and environmental impact | Construction Project Management (Site Visit)    | 117                                            | 30           | 1 | 2    | 4         |
|                                                 | Environmental impact of constructions           |                                                | 15           | 1 | 1    |           |
|                                                 | General Construction Processes                  |                                                | 21           | 2 | 1    |           |
| Management                                      | Intellectual Property Law                       | 114                                            | 9            | 1 | 1    | 4         |
|                                                 | Innovation & Entrepreneurship                   |                                                | 42           | 1 | 3    |           |
| Optional Teaching Unit                          | Structure                                       | Structural Dynamics                            | 42           | 2 | 3,5  | 10        |
|                                                 |                                                 | Stability of Buildings                         | 30           | 2 | 3    |           |
|                                                 |                                                 | Soils & Structures                             | 42           | 1 | 3,5  |           |
|                                                 | Roads and bridges                               | Roads and interchanges                         | 42           | 1 | 4    |           |
|                                                 |                                                 | Bridges & Tunnels                              | 42           | 1 | 4    |           |
|                                                 |                                                 | Pathology and maintenance of roads and bridges | 30           | 1 | 2    |           |
|                                                 | Natural Resources and Energy Studies            | Energy regulation of buildings                 | 42           | 1 | 4    |           |
|                                                 |                                                 | eco-construction                               | 30           | 1 | 2    |           |
|                                                 |                                                 | Natural resources engineering                  | 42           | 1 | 4    |           |
| Structures project                              | Structures project                              | 39                                             | 39           | 1 | 4    | 4         |
| Communication, Culture and Citizenship          | Communication, Culture and Citizenship English  | 42                                             | 42           | 1 | 3    | 3         |
|                                                 |                                                 |                                                | <b>342</b>   |   |      |           |
|                                                 |                                                 |                                                | <b>24,4</b>  |   |      | <b>30</b> |

## RESULTS AND DISCUSSION

The introduction of sustainability education in the program of civil engineering is not recent. It is outlined and well detailed previously (sterling, 2004; Kolmos et al, 2016). At the same topic, our experience details the results collected for forty years since including sustainability education in civil engineering programs.

The progress of academic training between the first and the final level shows a continuous implementation of sustainable development (Figure 4). For the development of each competence of engineering such as the fifth one (Taking into account environmental and societal constraints which presented in Figure 1), modules of the first level play the role of the prerequisite for the higher one. In fact, to make their solution RN2E project, students use their prerequisites from previous years as shown in Figure 4.

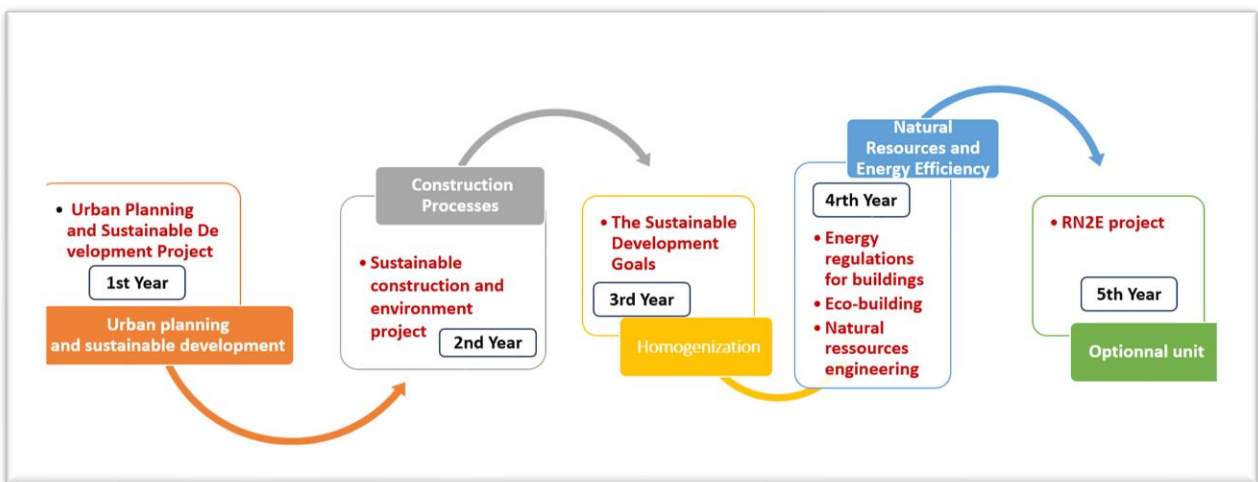


Figure 4. Prerequisite progress with the education level

Not only these prerequisites are used to develop the solution of each teamwork. Different numerical tools are used by students to concept their ideas. Artificial intelligence takes place also in the different work presented. It can also be shown that communication is very improved in teamwork and in the different expositions. Management of time and resources are also well-appreciated.

The combining units and the assessment methods are well appreciated by students. This fact is shown in the results of evaluation of lessons learned at the end of the improved unit. During the coaching sessions, teachers show an increase in motivation and autonomy of them. Professionals, who participate also on the study and coaching of Engineering training especially on the final level when studying the project appreciate the best practices used to improve the quality of education.

The exchange professionals-students are an occasion not only to share with them the professional experience but also to purpose internship and end-of-study internship.

On the same topic, and in the context of exchange, a seminar is also scheduled every year to sensitize students about the environmental problems. The first version, named Building of tomorrow, is focused on the ecological materials and the bioclimatic architecture. Engineers,

architects, professionals and academics explain the necessity of using local and green materials in construction. They presented their ecological projects to sensitize future engineers to develop their skills in the green buildings and open axes of research. On the second one, the engineer facing climate warming in Africa, African speakers participate in this event. Three different axes are presents: Drought and water management, Renewable Energy and finally Ecological materials and recycling. Students have understood that civil engineers must think about the environmental and societal constraints before construction and the necessity to introduce green energy and water management systems in the conception. On the third season, the committee think on the water problems and named this event The engineer facing the water crisis which takes place on April 2024.

These events are an opportunity for students to exchange with professionals and industrials, therefore, to understand the working environment and respect regulations and constraints in the national and international concept.

## **CONCLUSION**

This paper shared a broad approach that can be used by Civil engineering program seeking to integrate sustainable development into its curriculum using the CDIO Framework. Civil engineering is a discipline that incorporates many aspects: technological, economical, societal, and environmental ones. The approach of sustainability integration in the educational program in civil engineering aims to provide the foundational digital, human and sustainable development of future engineers and to apply them in searching solution on the ground.

This study is in accordance with the conclusion from Rosen (Rosen et al, 2021), in which, he used the SD standards for guiding and evaluating program development on the one hand and for evaluating and enhancing the status of sustainability in engineer program on the other hand.

The introduction of building information modelling (BIM) in these modules is the next step. This academic innovation will begin the next academic year. We estimate it will take three years to complete all modules.

Finally, our recommendation revolves around the necessity to introduce sustainability for all academics and create a multi-disciplinary project to improve the engagement of each one on the problems of society.

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# EVALUATE THE ENTREPRENEURIAL CAPACITIES OF SCHOOL OF ENGINEER: CASE STUDY ESPRIT

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## **ABSTRACT**

Entrepreneurship and innovation are two key elements for economic development. This is why the integration of entrepreneurial aspects into engineering training seems obvious and aligned with CDIO standards (especially optional standard 3). The creation of a new profile of engineers capable of combining technological innovation with business challenges and social development is not limited to the integration of entrepreneurship teaching but must be developed through the entrepreneurial university model. The university's openness to its economic and social environment has shifted its mission and role from that of a distributor of knowledge to a broader role as a generator of value. This extension of the mission has triggered the emergence of the entrepreneurial university concept. It is against this backdrop that this article, which focuses on assessing the entrepreneurial capacity of universities, has been drawn up, using the Esprit private college of engineering and technology as a case study. We are designing a quantitative approach that will enable us to understand practices within the university. This study will enable central universities to self-assess in relation to the context of entrepreneurial practices. The development of an evaluation model for the entrepreneurial university concerns our working methodology for measuring the entrepreneurial capacity of universities. This study consists of developing a methodological framework comprising the good entrepreneurial practices according to which the university will be assessed, and a mathematical aggregation model to determine the composite measurement indicator. This test of our evaluation method is based on a case study of the ESPRIT school of engineer.

## **KEYWORDS**

Entrepreneurship, Entrepreneurial engineering, Standard: 3

## LITERATURE REVIEW

The national innovation system is experiencing a notable increase in the importance of entrepreneurship opportunities (Hosseini et al., 2020; Ziyae et al., 2019), as it plays a vital role in driving economic growth through the creation of innovative solutions that arise from identifying market opportunities. The university, like any other organization, needs to adapt to this new paradigm to maintain and enhance its influence on the scientific, economic, and social environment. This is a key challenge for the higher education system, especially engineering schools, as they have the responsibility to provide individuals and societies with the necessary skills and knowledge to thrive in the future (OCDE 2022).

The opening of the university to its economic and social environment has developed its mission as much as that of distributor of knowledge towards a broader role and generator of value. This role expansion becomes especially urgent for engineering schools to create new student profiles capable of following rapid changes in society and working life and combining technological innovation with commercial challenges and social development. This is why universities are placing more and more emphasis on targeting engineering and science students with an entrepreneurial spirit (Venkataraman, 2004).

The definition of the entrepreneurial university concept is variable and depends on the culture of the academic community and how it shares this concept Marina Dabic (2017). Literature revealed a lack of a clear and unique definition for entrepreneurial universities; and it is due to the diversity of attitudes, cultures and values of academic community.

Indeed, the concept of the entrepreneurial always remains subjective and depends on the experience, the attitude, the belief and the culture of the population questioned about this concept, causing a certain diversity and relativity in the definition of the concept. By examining the literature, the entrepreneurial university is not limited on is typically linked to several concepts such as partnership with industry, the commercialization of knowledge produced, and research findings (Klofsten & Jones-Evans, 2000; Roessner, 2013).

The perspectives toward the entrepreneurial university would very depending on the actor that has been questioned.

The development of the university role from its traditional mission, centered on teaching and research; towards its third mission becomes a necessity to survive in the current economy. The transition to entrepreneurial universities has been and will continue to disrupt national and regional development as well as international competition. This is why universities are faced with the need to self-assess in relation to their practices and strategies, in order to be able to adapt to this flow. It is within this context that the present study is situated.

This paper is organized as follows: Section1 literature review, section 2 presents the research design while section 3 the case study.

## RESEARCH DESIGN

### *Research Method*

The aim of our study is to determine an assessment of good university entrepreneurial practices in the African context, for this our work will be divided into 3 main steps.

- **Step1:** We will start by determining the criteria for evaluating entrepreneurial capacity that reflect the good entrepreneurial practices of the university. The choice of these criteria will be essentially based on the bibliography and especially the challenges of the African context.
- **Step2:** consists in determining the importance of each criterion of the methodological framework. We start with a first phase which consists of carrying out a binary comparison followed by a calculation of the priority of each criterion based on the opinions of the experts consulted during our study. We adapt in this phase the Analytic Hierarchy Process AHP method (Saaty, 1990). The second phase consists in determining the weights of each criterion by the aggregation of the weights assigned by the expert using the Group Decision Making (GDM) .
- **Step3:** The last step of the evaluation process developed concerns the calculation of the overall score through the calculation of the composite index by the weighted sums method (SAW)( Afshari2010), this step will be carried out after having drawn up a questionnaire reflecting good practices these questionnaires will be used to collect information and to develop our quantitative study concerning our case. The methodology adopted for the assessment of university entrepreneurial practices is described in detail in figure i in the Appendix.

### *Conceptual Framework*

Based on the literature review, we chose to develop 7 criteria that describe good practices for an entrepreneurial university (table 1). During the development of our study framework, we took into consideration the review of the literature and we tried to enrich it, the integration of factors that seem important to us is adapted to the context of African universities. We have taken into consideration the very low employability rate, also a financial dependence on the government which is generally characterized by an inability to finance and the language barrier. The hierarchical structure of this research decision problem is shown in figure i in the appendix. The criteria that make up our methodological framework are as follows.

### *Policies and governance*

According to Clark (1998), an Entrepreneurial University, on its own, seeks to innovate in how it goes to business. It seeks to work out a substantial shift in organizational character so as to arrive at a more promising posture for the future. (Gibb and Hannon 2005) explain from their part that Universities organizational structure should be designed as to promote and facilitate entrepreneurial behavior based on these assertions on the part of several authors in the literature. We have proposed this dimension which describes the strategic orientation of the university and its vision to establish the entrepreneurial aspect, this is reflected by the commitment of the institution, governance and risk taking and rules and law.

### *Entrepreneurial culture*

Several authors in the literature have agreed on the importance of establishing an entrepreneurial culture in the universities to promote the entrepreneurial model of the latter. He considers this criterion to be an essential dimension for all entrepreneurial universities, one cites for example Sporn (2001: p. 132) explains that “an entrepreneurial culture will help universities to develop a new climate for innovation and change”.

### *Resources and capabilities*

In its resource-based approach, Guerrero & Urbano (2012) introduced the internal capacities and resources of the university as effective factors in the development of the entrepreneurial concept within these institutions. These internal resources of the university can be physical not concerning the adequate infrastructure or financial good by funds, aid to research. Zaharia & Gibert (2006) in their article entitled "The Entrepreneurial University in the Knowledge Society we considered that the management of this capital is among one of the 4 factors around which the strategy of transformation of the company is articulated to ensure transition from traditional university into an entrepreneurial university.

### *Education and research Teaching and research*

Teaching and research are part of the former missions of the university, fundamental functions of universities, which have been supplemented and extended by the entrepreneurial mission through the opening of the university to its external environment. To transform itself into an entrepreneurial university, and as already indicated, the university must act internally by setting up an entrepreneurial culture, of which education is one of the means of doing so, In this context (European Commission 2012) affirms that education more specifically entrepreneurial education is a key element to stimulate entrepreneurship in students who can acquire entrepreneurial skills and transform their profiles from job seeker into entrepreneurial job creators. Likewise, the university must also act externally to its environment by marketing research activities. We have chosen to divide this dimension into 3 sub-dimensions which are entrepreneurial education, teaching method and research and interdisciplinary.

### *Entrepreneurship support*

According to (Guerrero et al., 2015) Entrepreneurial universities are facilitators of economic development focused on entrepreneurship and this through institutional contexts conducive to entrepreneurial activities. This institutional context is essentially reflected in the structure of support and accompaniment of entrepreneurship. These structures are intermediaries that drive technological advances and facilitate the process of technology diffusion through the development of an environment that stimulates collaboration between universities, industry, and other actors in society. Entrepreneurship support aims to support the creation of new businesses, including small businesses and research groups (Redford 2014). It offers a variety of services such as mentoring, coaching, financing, advice, incubation.

### *Entrepreneurial and innovation impact*

An entrepreneurial university should be seen as a big influent stakeholder in the entrepreneurship ecosystem. Many authors in the literature (Sporn, Estkowitz) link the definition of entrepreneurial university to the exploitation of research results and an involvement in regional development. This dimension essentially deals with the outcomes of entrepreneurial universities in terms of commercialization of research results, of the impact of

these results on the regional and territorial economic level. The commercialization of research is the output of the entrepreneurial university. This dimension is evaluated through Academic spin off spin off, patent, patent. The importance of these achievements of the entrepreneurial university is underlined by (Lockett et al., 2005). In this context the author indicates that the concept of entrepreneurial university is wrongly associated simply with the technological commercialization of research and the number of patents, licenses, research projects and spin-off companies” (Lockett et al., 2005 of research., and the number of patents, licenses, research projects.

Table1. The good practices for an entrepreneurial university based on our framework

| <b>Dimensions<br/>(Criteria)</b>      | <b>Practices</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>C1. Policies and governance</i>    | <ul style="list-style-type: none"> <li>-The university has ingrained an entrepreneurial spirit into its core ethos, with a clear vision and mission that showcases its dedication to fostering entrepreneurship.</li> <li>-The university maintains autonomy in its governance and decision-making, while also committing to transparency and continuous improvement through regular evaluations of its entrepreneurial activities</li> <li>-The universities Allocate funds and resources for innovative projects involving staff, teachers and students.</li> <li>-The university Establish a Proactive Intellectual Property Framework: Form a legal advisory council to actively protect intellectual property and ensure the security of research outcomes and patents, while also implementing clear and comprehensive guidelines to provide a robust legal structure for the entire university community.</li> </ul>                                      |
| <i>C2. Entrepreneurial culture</i>    | <ul style="list-style-type: none"> <li>- The university has established a formal process for managing ideas, from their inception to evaluation, fostering a systematic approach to innovation.</li> <li>- Staff and students are encouraged to engage in innovative activities, supported by a dynamic environment that includes competitions and entrepreneurial clubs.</li> <li>- Entrepreneurship is deeply embedded in the university’s culture, with regular events and activities that promote this mindset, and it’s a significant factor in staff appraisals.</li> <li>- The university supports global engagement by using English as the medium of instruction and offers personal development resources, including well-being centers and life skills training.</li> </ul>                                                                                                                                                                           |
| <i>C3. Resources and capabilities</i> | <ul style="list-style-type: none"> <li>-The university Recognize and cultivate the expertise of employees, whether they specialize in one area or possess multidisciplinary skills.</li> <li>-the university has essential material resources like co-working spaces, laboratories, and research centers to support academic and entrepreneurial activities.</li> <li>-The university Maintain a portfolio of immaterial resources, including publications and intellectual property assets such as patents, trade secrets, copyrights, and trademarks, as well as software and codes.</li> <li>-Alternative Income Sources: Develop alternative income sources for the university, such as renting out facilities, laboratories, and residences.</li> <li>-The university Allocate financial capital specifically for entrepreneurship and the creation of new ventures, fostering an environment that supports innovation and business development.</li> </ul> |

|                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|--------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><i>C4. Education and research<br/>Teaching and research</i></p> | <ul style="list-style-type: none"> <li>-The university curriculum includes mandatory entrepreneurship courses to ensure that all students gain foundational knowledge in starting and managing businesses.</li> <li>-The university is proactive in recruiting individuals who specialize in entrepreneurship, enriching the academic environment with their expertise and experience.</li> <li>-Dedicated research programs in entrepreneurship are conducted at the university, promoting innovation and scholarly inquiry into the field.</li> <li>-The university has a track record of publishing scientific papers on entrepreneurship in peer-reviewed journals</li> <li>-The university employs various active teaching methods, including competency-based approaches, and project-based learning, to cater to diverse learning preferences and educational outcomes.</li> </ul> |
| <p><i>C5. Alliance and network</i></p>                             | <ul style="list-style-type: none"> <li>- The university establish collaboration contracts with: Academic partners<br/>Industrial partners, public sector.</li> <li>The university has a significant proportion of co-authored work with industrial partners.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <p><i>C6. Entrepreneurship support</i></p>                         | <p>The universities Offer robust support services, including advisory services for startups, which are vital for guiding young entrepreneurs through the early stages of business development.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <p><i>C7. Entrepreneurial and innovation impact</i></p>            | <ul style="list-style-type: none"> <li>- University focus on achieving impactful research outcomes, including the development of spin-offs, academic entrepreneurship, licensing agreements with national companies or local startups, and the commercialization of research projects within the industry.</li> <li>-The university is encouraged to actively participate in social and regional projects, contributing to the development and well-being of the surrounding areas.</li> <li>-The university prioritizes attention to Sustainable Development Goals (SDG) in its operations and academic programs.</li> </ul>                                                                                                                                                                                                                                                             |

### **Mathematical Aggregation Formulation**

*Determining the weighting associated with the frame dimensions.*

The calculation of the weights of the criteria composing our methodological framework will be through the AHP method combined with the GDM method which will allow us to quantify the importance of the criteria to subsequently calculate the composite index.

In order to complete this step, we created a questionnaire and sent it to a panel of experts in a variety of areas, such as entrepreneurship, innovation, and university education. The experts answered to the pre-made questionnaire, which contained the dimensions (or criteria) that needed to be weighted. Eight pairwise matrices were included in the questionnaire; one matrix, with size seven, represented the first level of the developed conceptual framework, and seven more, with sizes ranging from two to five, represented the second level of the framework. An example of these matrices is illustrated in Table 2. Following the processing of the data, we noted an inconsistency in the weighting logic of 2 experts in fact, the results of the weighting a

consistency ration not accepted, for a time constraint which prevented us from making feedback and correcting them. Necessary, we were satisfied with 6 experts.

Table 2. Pairwise comparison matrix relating to the dimension Policies and governance

| <b>Matrix</b>                           | Institutional commitment | Governance Structure and risk taking | Rules and Laws | Government and administrative Framework | Monitoring and Evaluation |
|-----------------------------------------|--------------------------|--------------------------------------|----------------|-----------------------------------------|---------------------------|
| Institutional commitment                | 1                        | 1/2                                  | 1/2            | 1/3                                     | 2                         |
| Governance Structure and risk taking    | 2                        | 1                                    | 1              | 1                                       | 1/2                       |
| Rules and Laws                          | 2                        | 1                                    | 1              | 1                                       | 2                         |
| Government and administrative Framework | 3                        | 1                                    | 1              | 1                                       | 2                         |
| Monitoring and Evaluation               | 1/2                      | 2                                    | 1/2            | 1/2                                     | 1                         |

### Application of GDM ET AHP

After determining the weights relating to each criterion according to the opinions of the selected experts, we applied the methods of aggregating individual judgments to obtain the overall weight more precisely, the AIP technique, the aggregation of individual priorities. The weights are then determined by applying the geometric means of the individual priorities and normalizing the values obtained.

Table 3 represents the weights relating to the criteria of the first level of the framework of the entrepreneurial university.

Table3. Table of weights relating to the criteria to criterion C1 Policies and governance

|                                                     | Exp1  | Exp2  | Exp3  | Exp4  | Exp5  | Exp6  | Standardized weight W' | Rank |
|-----------------------------------------------------|-------|-------|-------|-------|-------|-------|------------------------|------|
| <b>C11: Institution Commitment</b>                  | 0.097 | 0.108 | 0.198 | 0.181 | 0.094 | 0.076 | 0.128                  | 5    |
| <b>C12: Governance structure and risk taking</b>    | 0.203 | 0.424 | 0.13  | 0.364 | 0.194 | 0.113 | 0.233                  | 1    |
| <b>C13: Rules and Law</b>                           | 0.254 | 0.143 | 0.184 | 0.239 | 0.194 | 0.257 | 0.228                  | 2    |
| <b>C14: Government and administrative framework</b> | 0.183 | 0.255 | 0.185 | 0.108 | 0.195 | 0.198 | 0.192                  | 4    |
| <b>C15: Monitoring and Evaluation</b>               | 0.263 | 0.07  | 0.303 | 0.108 | 0.233 | 0.356 | 0.219                  | 3    |
| <b>RC (≤ 0,08)</b>                                  | 0.07  | 0.05  | 0.08  | 0.02  | 0.05  | 0.08  |                        |      |

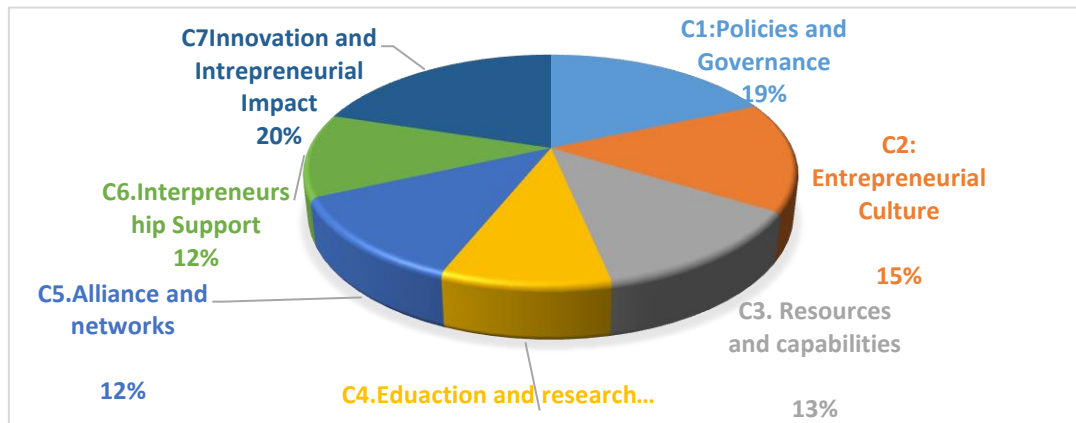


Figure 2. The wight distribution of the first level criteria of our methodological framework

After the synthesis of the weighting results of the first-level criteria of our methodological framework (figure2) we find that the weights of the level 1 criteria are distributed according to 4 levels: The first is composed of the following criteria "Innovation and entrepreneurial impact" with a weight equal to 20% followed by the criteria policies and governances with a variation of 2% or 18% of the total weight of level 1 of the framework. These two criteria are the most important in terms of weight distribution, with an overall weight of 38%, accounting for almost one-third of the total weight of Level 1 of the frame. This value indicates the importance of this factor in relation to the specialist in the process of evaluating the entrepreneurial university, if we analyze more closely, we find that these two criteria present criteria of entry and exit from the process of university entrepreneurship. The entry criteria are translated by, policy and governance, whether internally through the university's engagement, these values and its entrepreneurial vision or even externally through the flexibility of government governance translated into an entrepreneurial strategy that offers a university an Independence enabling it to work in an environment conducive to entrepreneurship and creativity. The second level Include the second criterion of the framework «the entrepreneurial culture» of weight equal to 16% of the total weight of the level 1 of the framework. With this weighting, the specialists express the importance of establishing the entrepreneurial culture within the university to facilitate its transformation. Fostering the community's commitment toward entrepreneurship. The third level includes the entrepreneurship support and alliance and network criteria, each with an equal weight of 12 and the Resources and capabilities dimension with a slight increase of 1%. In the last level, we find the education and research dimension in the last rank with a weight of 9% of the total weight. In the final step, the education and research dimension is ranked last with a weight of 9% of the total weight. The experts considered that key factors for assessing the entrepreneurial capacity of the university are governance, culture, alliance and resources. their choices from our point of view are inspired by places experience within the Tunisian academic or industrial environment this environment develop the embryonic situation of mechanisms that boost academic entrepreneurship that essentially feel most weighted criteria of the experts' share.

Similarly in Africa, African universities suffer from the same problem in terms of governance and Independence from university to government. On the other hand, the experts say that the criteria education and research is development is the least important it is induced according to our opinion, to the fact that these criteria are considered on the part of the specialists and



acquired for any university since they present the first and second mission of the traditional university.

### **CASE STUDY: ASSESSMENT OF THE ENTREPRENEURIAL CAPACITY OF ESPRIT**

This part will be devoted to the implementation and the testing of our work. We then chose the private higher school of engineering and technology of Tunis ESPRIT as a case study to evaluate these practices in relation to our framework to design Entrepreneurial university. To give him recommendations on the one hand and to improve our framework on the other hand.

#### **Data Collection**

To collect information on the degree of application of good practices relating to our methodological framework of the entrepreneurial university, we carried out a quantitative study to develop a questionnaire which reflects quantifiable, observable and measurable practices. We have developed a questionnaire of 52 questions which reflect all the good practices developed at the level of dimension and sub-dimension of our Framework. We have opted for closed questions to minimize the error did not direct the answers.

Table4 shows an example of a yes or no question and an example of a multiple-choice question for the first dimension of our framework.

Table 4. Example from the survey

| <b>C1- Polices and Gouvernance</b>                                                                         |           |                       |
|------------------------------------------------------------------------------------------------------------|-----------|-----------------------|
| <b>C12. Governance structure and risk taking</b>                                                           |           |                       |
| Are there any innovative projects funded by the university?                                                | Yes       | <input type="radio"/> |
|                                                                                                            | No        | <input type="radio"/> |
| Are there any innovative projects funded by the university in collaboration with?<br>Check all that apply. | Staff     | <input type="radio"/> |
|                                                                                                            | Teachers  | <input type="radio"/> |
|                                                                                                            | Students  | <input type="radio"/> |
|                                                                                                            | Graduates | <input type="radio"/> |

#### **Data analysis (saw method)**

After assigning weights to the different dimensions (criteria) of our entrepreneurial university framework we start to calculate the composite index.

The composite index will be calculated using the Simple Additive Weighting (SAW) method. Which is also known as weighted linear combination or scoring methods Simple Additive (Afshari2010), SAW is a simple and most often The calculation of the composite index by the Simple Additive Weighting (SAW) method is summarized in three steps as shown in the table.i in the appendix .

### *Step 1: Calculation of local scores*

We will begin by calculating the scores related to the different dimensions, which we will refer to as local scores for ESPRIT. The local score is the total score awarded to Esprit by summing its responses for each dimension. An example of the methodology for assigning scores to responses for the fifth dimension is outlined in detail in Table 5.

Table 5. Summary of the question scoring methodology for the 5th dimension "Alliances and networks."

| Section(s)                             | Question(s)                                                                                                    | Scoring Technique                                                                                                                                                      |
|----------------------------------------|----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sub-dimension                          | closed – end question: yes or No question or question with unique choice                                       | 0 pts; if 0 Reponses is « No »<br>4pts, if 1 Reponses is « Yes »                                                                                                       |
| C51. Public<br>Private<br>Partnerships | Does the university have collaboration contracts with Academic partners<br>Industrial partners' public sector. | 0 pts; if 0 Responses is «No »<br>1 pts; if 1 Responses is «Yes »<br>2 pts; if 2 Responses is «Yes»<br>3 pts; if 3 Responses is «Yes»<br>4 pts, if 4 Responses is «Yes |

The local (individual) scores, which assess the performance across various dimensions (levels 1 and 2), will be derived from the responses to the questionnaires intended for the university in our case study, ESPRIT.

### *Step 2: Normalization of Individual Scores*

To increase its reliability, the weighted sum method requires the use of comparable scales. Therefore, we will proceed to normalize the individual scores. This normalization aims to free us from the units specific to each of the original scales. The table i in the appendix summarizes the weighted scores and the individual scores of the ESPRIT University.

### *Step3: Calculation of the composite index*

Table 6 represents the composite index of ESPRIT and details his current situation to have this score.

Table 6. Calculation of the composite index (overall scores)

| <i>Dimension</i>                             | <i>ESPRIT</i> | <i>Status</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | <i>Composite index</i> |
|----------------------------------------------|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|
| <i>Policies and Governance</i>               | 0.397         | <p>- Esprit do not Allocate funds and resources for innovative projects involving staff, teachers and students.</p> <p>-Esprit didn't have a clear vision and mission that showcases its dedication to fostering entrepreneurship.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 0.554                  |
| <i>Entrepreneurial Culture</i>               | 0.657         | <p>Esprit Offer a dynamic environment to encourage students and teachers but not staff to engage in innovative activities, supported by that includes competitions and entrepreneurial clubs.</p> <p>- Entrepreneurship is deeply embedded in the university's culture, with regular events and activities that promote this mindset, and it's a significant factor in staff appraisals.</p> <p>-ESPRIT has made strides in supporting global engagement by adopting English as the medium of instruction and providing personal development resources, such as well-being centers and life skills training. However, these initiatives have not yet been fully realized to their utmost potential.</p> |                        |
| <i>Resources and Capabilities</i>            | 0.65          | -Esprit knowledge and fosters the talents of its staff, who may be experts in a specific field or have a broad range of skills. is equipped with vital physical resources, including shared workspaces, labs, and research facilities, which are instrumental in advancing scholarly and business initiatives.                                                                                                                                                                                                                                                                                                                                                                                          |                        |
| <i>Education and research</i>                | 0.896         | <p>-ESPRIT supports, promotes, and evaluates the development of entrepreneurial skills.</p> <p>ESPRIT stands out in Tunisia for its innovative educational approaches. By embracing active teaching methods like competency-based approaches and project-based learning</p>                                                                                                                                                                                                                                                                                                                                                                                                                             |                        |
| <i>Alliance and networks</i>                 | 0.874         | ESPRIT is committed to fostering cross-sectoral partnerships, promoting international experiences, and strengthening the global relevance of its educational programs.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                        |
| <i>Entrepreneurship measure</i>              | 0             | Total absence of service support for entrepreneurs such as Innovation clusters, Incubation spaces, Technological parks, Knowledge transfer Office                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                        |
| <i>Innovation and entrepreneurial Impact</i> | 0.524         | <p>- ESPRIT actively participates in social and regional projects, contributing to the development and well-being of the surrounding areas.</p> <p>-The university prioritizes attention to Sustainable Development Goals (SDG) in its operations and academic programs.</p>                                                                                                                                                                                                                                                                                                                                                                                                                            |                        |

## RESULTS AND DISCUSSION

Esprit got a very high score when it comes to teaching methodology, which is implied by this extreme university's policy of engaging in the application of active competency-based pedagogy and problem-solving real. Problem and Project Based Learning (PBL) remains at the heart of ESPRIT's pedagogy. This practice aims to put the engineer at the core of the process (collaborative projects and simulation activities) by tackling current themes each. Another reform has been put in place to integrate innovation and entrepreneurship modules into the study plans of studies in different disciplines. This module allows engineers to accumulate basic knowledge on business creation and the world of business. Familiarization of engineer with the concept of entrepreneurship through entrepreneurship education, of course is very important but it is not sufficient to really boost innovation and creativity, support measures must be put in place to try to propose innovative ideas, and to follow the advice and incubation of projects, these services can be intended for the whole university family. Despite the importance of these measures, we notice that in the case of ESPRIT, they are totally absent. Although the school has tried to set up an internal support service called ESPRIT UNCUBATION, which has offered ENGINEERS and staff support and incubation services and even funding that helps them in their entrepreneurial journey. Although the resources and the means of support existed, this structure was not successful in terms of incubated projects, in fact the number of people who consulted this structure was very modest. This failure may be due to a lack of an entrepreneurial culture at the time or to resistance to change on the part of the university community. Which does not lead to the question, is there an order of priority for the application of entrepreneurial practices and what is its impact on the success of the process of transforming universities into an entrepreneurial university?

According to the results, several measures can be taken to improve the entrepreneurial capacity of ESPRIT, among which:

- Establishment of strategic entrepreneurial plans that contain the entrepreneurial goals and missions of the university at cost and in the medium term.
- Involve alumni in entrepreneurial activities through conferences or even summer camp activities which revolve around entrepreneurship.
- Set up a structure dedicated to entrepreneurship such as the hunter center made up of early-stage investors and industry experts who have a passion for supporting student-led entrepreneurial activity.
- Encourage co-creation with students and staff.
- Participate in modern entrepreneurial competition, to strengthen the partner network.
- Made entrepreneurial activities an integral part of our engineer's education.
- embeds voluntary projects in modules and extracurricular projects as well as in research and consultancy.

## CONCLUSION

The injection of the entrepreneurial concept into the university usually requires the reform or a complete transformation of the university practices. At the internal level, the organization need to establish the entrepreneurial culture first within its entities to ensure a continuous monitoring of the market and so promoting marketing research through the creation of alliances and collaborations with its environment. This paper describes a method for evaluating the capacity of universities to appraise their performance in regard to degree of application of entrepreneurial practices. The concept of entrepreneurial universities is a dynamic concept and variable, it depends on several factors including the environment; culture and altitude and he facilitate the creation of the entrepreneurial engineer.

The teaching of entrepreneurship is one of the parameters of the entrepreneurial university model but to truly succeed in the third mission, to spin out knowledge-based businesses, to create employment, and to generate socio-economic value The university must collaborate with stakeholders in its environment, particularly government and industry. The university must then react:

- Internally through its governance and its teaching method through designing of learning experiences around real-life settings, encouraging prototyping of experimentation.
- Externally in relation to its environment through collaboration, the search for investors, funds, the commercialization of research.

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APPENDIX

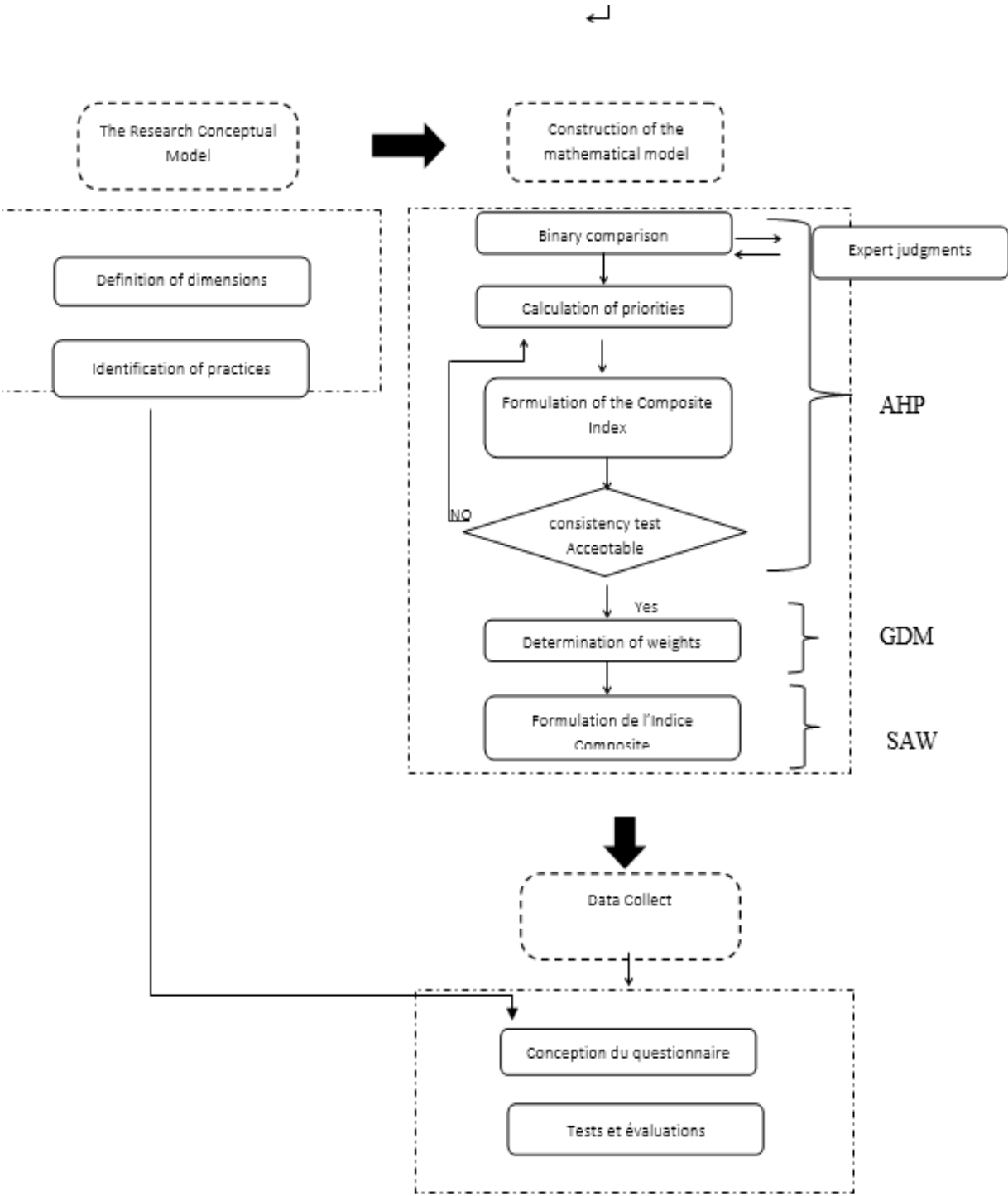


Figure i. The methodology for evaluating the entrepreneurial capacities of universities. (Ben Younes,2013)

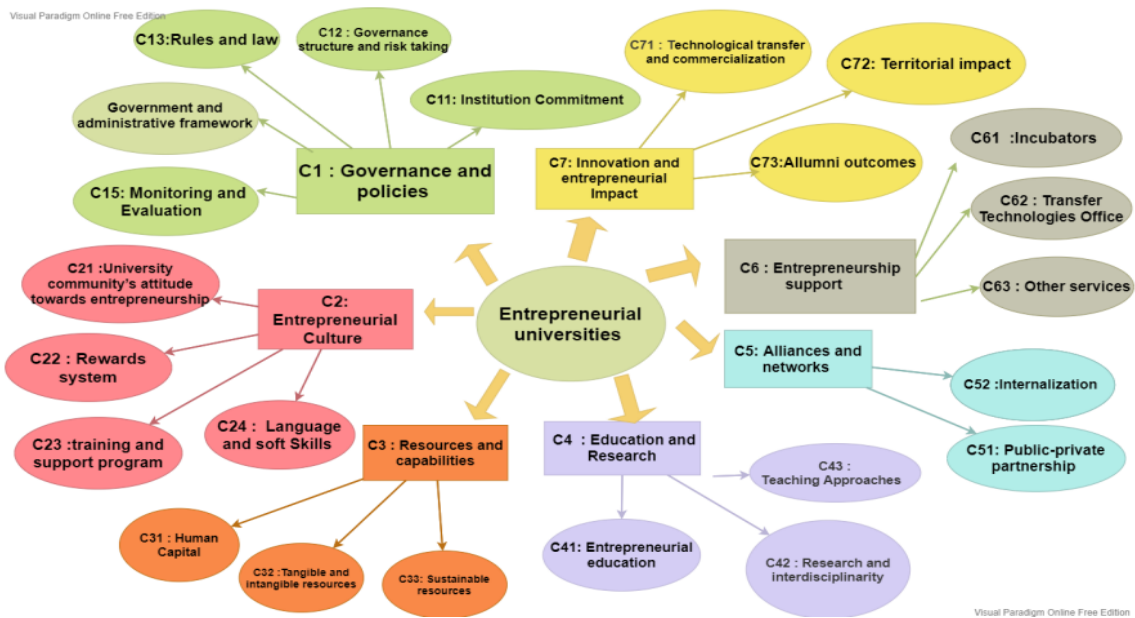


Figure ii. The Research Conceptual Model

Table i. The algorithm for calculating the composite index: Saw method (Afshari2010)

| <b>Step 1: Calculation of Individual (Local) Scores</b>                                                                       |                                                                                                                                                                                                                                                                                                                   |
|-------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $S_j = \sum_{k=1}^{n_j} S_{jk} \text{ avec } k = 1, \dots, n_j$                                                               | <ul style="list-style-type: none"> <li>• <math>S_j</math>: individual score at the dimension (j);</li> <li>• <math>(n_j)</math>: total number of questions for dimension (j);</li> <li>• <math>(S_{jk})</math>: score associated with question (k) at the dimension (j).</li> </ul>                               |
| <b>Step 2: Normalization of Individual Scores</b>                                                                             |                                                                                                                                                                                                                                                                                                                   |
| $S'_j = \frac{S_j}{\sum_{k=1}^{n_j} S_{jkmax}} \text{ avec } k = 1, \dots, n_j$                                               | <ul style="list-style-type: none"> <li>• <math>(S'_j)</math>: normalized individual score at the dimension (j)</li> <li>• <math>(S_j)</math>: individual score at the dimension (j)</li> <li>• <math>(S_{jk}\{max\})</math>: maximum score that can be achieved for question (k) at the dimension (j).</li> </ul> |
| <b>Step 3: Calculation of the Composite Index (Global Score)</b>                                                              |                                                                                                                                                                                                                                                                                                                   |
| $Scor(E_i) = \sum_{j=1}^n W'_j S'_j \text{ avec } j = 1, \dots, n, \sum_{j=1}^n W'_j = 1 \text{ et } 0 \leq Scor(U_i) \leq 1$ | <ul style="list-style-type: none"> <li>• <math>(U_i)</math>: University (i);</li> <li>• <math>(W_j)</math>: weight related to dimension (j);</li> <li>• <math>(S_j)</math>: normalized individual score at the dimension (j);</li> <li>• <math>(n)</math>: total number of dimensions.</li> </ul>                 |
| $Score(U_j) < Score(U_i)$ if the university i develop more entrepreneurial than university j                                  |                                                                                                                                                                                                                                                                                                                   |



Table ii. The weighted scores and the individual scores of the ESPRIT University

| Criteria                                  | Sub-Criteria                                                  | ESPRIT             |
|-------------------------------------------|---------------------------------------------------------------|--------------------|
|                                           |                                                               | Standardizes Score |
| C1: Policies and Governance               | C11: Institution Commitment                                   | 0.50               |
|                                           | C12: Governance structure and risk taking                     | 0.00               |
|                                           | C13: Rules and law                                            | 0.50               |
|                                           | C14: Government and administrative framework                  | 0.00               |
|                                           | C15: Monitoring and Evaluation                                | 1.00               |
| C2: Entrepreneurial Culture               | C21: University community's attitude towards entrepreneurship | 0.71               |
|                                           | C22: Rewards system                                           | 1.00               |
|                                           | C23: Training and support program                             | 0.25               |
|                                           | C24: Language and soft Skills                                 | 0.67               |
| C3: Resources and capabilities            | C31: Human Capital                                            | 1.00               |
|                                           | C32: tangible and intangible resources                        | 0.88               |
|                                           | C33: sustainable resources                                    | 0.50               |
| C4: Education and research                | C41: entrepreneurial education                                | 1.00               |
|                                           | C42: Research and interdisciplinarity                         | 0.67               |
|                                           | C43: teaching Approaches                                      | 1.00               |
| C5: Alliance and networks                 | C51: public-private partnership                               | 0.63               |
|                                           | C52: Internalization                                          | 1.00               |
| C6: Entrepreneurship measure              | C61: Incubators                                               | 0.00               |
|                                           | C62: Technology Transfer Center                               | 0.00               |
|                                           | C63: Other services                                           | 0.00               |
| C7: Innovation and entrepreneurial impact | C71: Technological transfer and commercialization             | 0.25               |
|                                           | C72: Territorial impact                                       | 1.00               |
|                                           | C73: Alumni outcomes                                          | 0.25               |

# THE ENCORE PROJECT: SUPPORTING EDUCATIONAL DESIGN WITH NATURAL LANGUAGE PROCESSING

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## ABSTRACT

ENCORE (ENriching Circular use of OER for Education) is an Erasmus+ project. This paper introduces the ENCORE approach, a novel strategy developed to address the challenges of the digital era in engineering education. ENCORE harnesses the potential of OER combined with the advancements in Natural Language Processing (NLP) and artificial intelligence, linking educational content with relevant skills in the European Skills, Competencies, Qualifications, and Occupations (ESCO) framework. The approach is designed to enhance the reuse of OERs, integrating them with data-driven tools and pedagogical guidelines to facilitate effective course design and outcome evaluation. This paper particularly explores the integration of the ENCORE approach within the CDIO (Conceive-Design-Implement-Operate) framework, highlighting how it can assist educators in incorporating green digital and entrepreneurial skills into engineering courses. The core elements of ENCORE, including a specialized database and ENCORE enablers, are outlined, emphasizing their role in crafting relevant learning paths and enriching engineering education. The paper concludes with a forward-looking perspective on the future development of ENCORE, focusing on its testing and refinement in engineering education through upcoming staff development activities and pilot testing, underscoring the importance of its alignment with the CDIO framework in enhancing the learning experience in the rapidly evolving landscape of engineering education.

## KEYWORDS

Open Educational Resources, Natural Language Processing, Engineering Education, Digital Skills Development, Sustainable Educational Practices, Standards: 2, 6, 9

## INTRODUCTION

In the contemporary digital era, educational methodologies and institutional models are experiencing profound transformations. The shift from traditional classroom learning to digital platforms enables learning anytime, anywhere (Kaplan, 2022). This evolution demands new competencies in anticipation, adaptability, and decision-making under uncertain conditions. However, the educational sector (also engineering education) often lags in adapting to these social and technological shifts.

The plethora of information and emerging technologies necessitates pedagogical strategies grounded in robust scientific and technical knowledge. The pressing challenges of the 21st century, such as climate change and digitalization, underscore the need for updated teaching and learning methods. The COVID-19 pandemic has further accentuated this urgency, presenting a crossroads for educational reform (Williamson, Eynon, & Potter, 2020). A paradigm shift from mere knowledge dissemination to flexible, proactive methods employing automation and Artificial Intelligence (AI) is essential. This requires educators to rethink their practices and engage actively in designing and debating educational interventions that foster technologically advanced, sustainable, and resilient societies (Goodyear, 2015).

In the European context, policies and initiatives aim at digital transformation while ensuring inclusive and sustainable growth. The "A strategy for smart, sustainable and inclusive growth" policy underscores the balance between technological progress, sustainability, and social inclusion. The Digital Education Action Plan (2021-2027) and the updated Digital Competence Framework reflect the EU's commitment to adapting education to the digital age, particularly in the wake of the pandemic and climate change (Commission, 2020). The European Skills Agenda, part of the European Digital Strategy, focuses on skill development and utilization in response to digital transformation and the transition to a climate-neutral Europe.

The abundance of open educational resources (OERs) presents significant opportunities for education, allowing educators to focus on value-added activities (Wiley, Bliss, & McEwen, 2014). However, this shift calls for a transition from open educational resources to open educational practices. The EU supports this through various initiatives, including the Joint Research Centre's "Opening up Education: A Support Framework for Higher Education Institutions" and the Open Education Europa platform (dos Santos, Punie, Muñoz, et al., 2016). However, the global movement towards OER usage, especially during the COVID-19 emergency remote teaching, has highlighted challenges in OER quality and usage (dos Santos et al., 2016).

Intelligent systems are increasingly developing educational tools to manage the abundance of resources. This evolution necessitates new approaches to skills recognition and certification, highlighting the potential of micro-credentials and open digital badges (Segarra-Faggioni & Romero-Pelaez, 2022b). These innovations, however, require further empirical research and expert insights for effective policymaking and user engagement.

Addressing these challenges, this paper introduces the ENCORE (ENriching Circular use of OER for Education) approach, a novel method to confront the digital era's educational challenges developed in the realm of the ENCORE project (<https://project-encore.eu/>). ENCORE leverages OER knowledge, applying Natural Language Processing (NLP) to link information with relevant skills in the European Skills, Competencies, Qualifications, and Occupations (ESCO) framework. It combines data-driven tools with pedagogical guidelines to

enhance the reuse of OERs. The paper also explores the integration of the ENCORE approach with CDIO to help educators to incorporate new content in engineering courses.

## **THE CORE ELEMENTS OF ENCORE: NATURAL LANGUAGE PROCESSING AND OPEN EDUCATIONAL RESOURCES**

This section synthesizes existing research on Natural Language Processing (NLP) applications in Open Educational Resources (OER) and topic extraction from education and labor market documents. Key insights are drawn from the literature, notably the works of Ferreira et al. Ferreira-Mello, André, Pinheiro, Costa, and Romero (2019), highlighting the state-of-the-art in NLP applied to educational resources.

OERs, encompassing a variety of educational materials like textbooks, videos, and lesson plans, are crucial for broad educational access. However, their effectiveness is often hindered by poor quality metadata, impeding resource discoverability (Tavakoli, Faraji, Mol, & Kismihók, 2020). This challenge is exacerbated as OER authors frequently overlook metadata creation due to its time-consuming nature. AI, particularly through NLP techniques, emerges as a solution for enhancing OER metadata by extracting key information from their content (SegarraFaggioni & Romero-Pelaez, 2022a).

NLP, a subset of AI, interprets human language in written form, and is pivotal in converting OERs into analyzable text (Tavakoli et al., 2020). A common NLP methodology in this context is topic modeling, with Latent Dirichlet Allocation (LDA) being widely used for identifying OER topics (Tavakoli et al., 2022). Nevertheless, LDA's unsupervised nature leads to varying topic detail levels (Puccetti, Giordano, Spada, Chiarello, & Fantoni, 2023). Addressing this, a balanced approach in topic identification is essential, avoiding overly abstract or specific terminologies to enhance educational resource recommendation systems.

Furthermore, defining 'education topics' is necessary to overcome LDA limitations (Nadeau & Sekine, 2007). Named Entity Recognition (NER) serves this purpose, classifying education-related topics in text. NER employs three main methods: gazetteer-based, rule-based, and machine learning-based (Giordano, Chiarello, Melluso, Fantoni, & Bonaccorsi, 2021; Giordano, Coli, & Martini, 2022).

Advancements in word embedding techniques have significantly impacted NLP. These techniques, including traditional (word2vec, GloVe) and contextual embeddings (BERT), have improved entity recognition efficiency (Mikolov, Chen, Corrado, & Dean, 2013). Parallely, NLP's role in labor market analysis is expanding, with applications in skill and knowledge extraction, relevant to both labor and education sectors (Spada et al., 2022).

Despite the limited application of NER in OER, the increasing integration of NLP to enhance OER quality and accessibility shows promise Gazzola et al. (2022). This integration aligns with the CDIO (Conceive-Design-Implement-Operate) framework in engineering education, where enhancing educational resources through AI and NLP can significantly contribute to the 'Implement' and 'Operate' stages. These stages focus on realizing and sustaining the educational approach, where AI-assisted metadata improvement and resource discoverability play a crucial role.

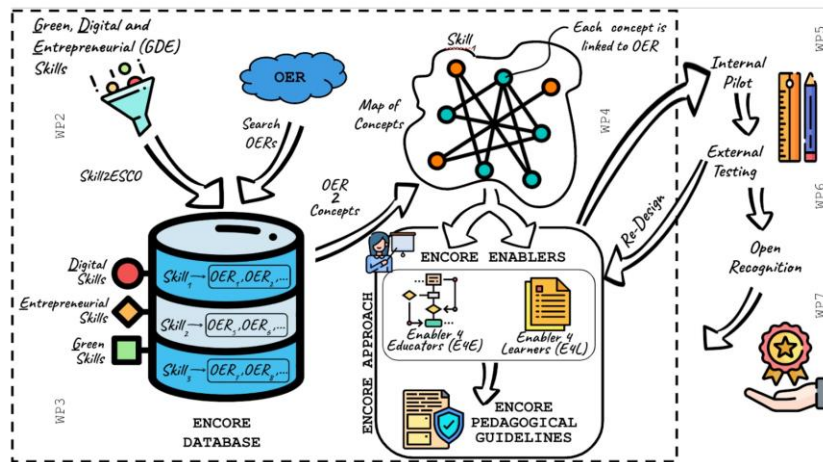


Figure 1. Diagrammatic representation of the ENCORE ecosystem, illustrating its components and the flow of information (from the ENCORE website)

## THE ENCORE METHOD

In light of the aforementioned context, this section delineates the conceptual framework and methodological underpinnings of our proposed solution, ENCORE. The primary aim of ENCORE is to enhance teaching methodologies and facilitate the recognition of skills pivotal to addressing contemporary macro-trends such as digitalization, environmental change, and the economic resurgence post-COVID. Our objectives are multifaceted: (1) Equip students and professionals with the competencies necessary to navigate economic, ecological, and technological shifts; (2) Address the skill gap between industry requirements and academic offerings; (3) Assist educators in keeping pace with the dynamic skill landscape; (4) Address the inertia in educational sector reforms; (5) Aid educators in adapting to evolving educational contexts with effective pedagogical strategies; (6) Assist students in authenticating skills acquired through unconventional pedagogical methods. Figure 1 synthetise the ENCORE method in graphical form.

Our strategy is to augment the teaching and recognition of skills impacted by these macrotrends, utilizing the wealth of information embedded in Open Educational Resources (OER)<sup>2</sup>. This will involve extracting knowledge from OER texts using Natural Language Processing (NLP), a field at the intersection of computer science, linguistics, and AI, which enables computers to comprehend and analyze human language. This methodology allows for the extraction of valuable insights from OER. Within this framework, our approach integrates data-driven tools for instructional design with pedagogical guidelines, steering educators towards effectively crafting courses that achieve desired learning outcomes and evaluate those outcomes. Our focus is on learning outcomes associated with skills necessary to confront challenges in digitalization, environmental change, and post-COVID economic recovery. This is further supported by leveraging another textual knowledge source, the ESCO (European framework of Skills, Competences, Qualifications and Occupations). Through NLP, OER content is scrutinized, and skills are identified and aligned with those listed in ESCO, leading to the creation of a specialized database categorizing OER and corresponding skills.

<sup>2</sup> <https://www.oercommons.org/>

Building on this knowledge base, we will develop the ENCORE methodology, which amalgamates data-driven tools and approaches for educational design with pedagogical principles. This will empower educators to effectively utilize ENCORE's technological resources in crafting courses that not only reach but also assess intended learning outcomes using open resources. A key ambition of the ENCORE strategy is to harness and repurpose OER, as well as to devise novel tools for both teaching and learning. Furthermore, the initiative advocates for an open methodology in recognizing learning outcomes, aligning with the European Union's ongoing micro-credentialing processes.

The ENCORE project adopts a technological ecosystem perspective, characterized by independent yet cohesive components. Central to this ecosystem is a database linking Open Educational Resources (OERs) to General Digitalization and Entrepreneurship (GDE) skills, alongside ENCORE enablers crafting relevant learning paths. This section outlines the ecosystem's key elements: the database and enablers, their architecture, and the pedagogical evaluation process for validation.

### **Database**

The ENCORE database forms the technological ecosystem's core, cataloging OERs and their association with GDE skills. Its design emphasizes robustness and adaptability, accommodating evolving OER and skill characterizations. This flexibility ensures minimal impact on the ecosystem during data schema modifications. Initially, the database will utilize the Dublin Core Metadata Element Set (DCMES), an open-standard metadata schema aligned with the database's goals of simplicity, understandability, international scope, and extensibility Kunze and Baker (2007); Weibel, Kunze, Lagoze, and Wolf (1998).

The database's development includes populating it with high-quality, relevant OERs. This involves assessing existing OER repositories, selecting pertinent resources, and extracting metadata and content using APIs or web scraping. Post-extraction, a quality filter vets each OER, followed by NLP techniques to identify and link relevant GDE skills.

Inter-component communication within the ecosystem is crucial. The ENCORE database features a REST API, facilitating metadata and content retrieval by other tools, notably the ENCORE enablers.

### **ENCORE Enablers**

The ENCORE enablers are designed to assist educators in creating effective learning paths. The Educator-for-Educator (E4E) Enabler aids in constructing these paths, which guide students towards intended learning outcomes (ILOs). This tool displays a proto-conceptual map of course concepts extracted from OERs, helping educators select concepts for inclusion and define progression criteria between them. Gamification techniques enhance the appeal and effectiveness of these paths. The E4E Enabler, an open-source software, incorporates gamification mechanics to motivate students, making learning paths both challenging and engaging.

For students, the defined learning path is transformed into an executable format through the Educator-for-Learner (E4L) Enabler. Utilizing Microsoft's open technologies and notebook software, this tool facilitates interactive learning and assessment. Notebooks combine fixed and editable text cells, allowing students to engage with materials and assessments designed by educators. The learning sequence in the notebook, derived from the E4E output, is further

enriched with gamification elements to boost student engagement. The E4L Enabler will also be released as open-source software, promoting interactive and engaging learning experiences.

## POSSIBLE INTEGRATION OF ENCORE AND CDIO APPROACH

The ENCORE approach, integrated within the CDIO framework, provides a novel pathway for educators to instill green digital and entrepreneurial skills in engineering education. This subsection delves into how ENCORE’s database of Open Educational Resources (OER), focused on these key skill areas, aligns with the CDIO syllabus’ phases - Conceive, Design, Implement, Operate - enriching the curriculum content with practical, sustainable, and innovative perspectives.

Table 1 highlights specific contributions, advantages for educators and students, and potential challenges.

### **Conceive Phase**

In the ‘Conceive’ phase, where students learn to conceptualize new systems and products, ENCORE plays a crucial role by offering OERs centered around green digital technologies and entrepreneurial thinking. This integration allows students to explore sustainable and innovative approaches from the conception stage of engineering projects. For educators, ENCORE provides a diverse range of resources to demonstrate the importance of sustainability and innovation in the early stages of engineering design.

### **Design Phase**

During the ‘Design’ phase, students engage in creating detailed plans for engineering systems. ENCORE enriches this phase by providing access to OERs that highlight green design principles and digital innovation strategies. Utilizing NLP, ENCORE can selectively present design concepts that emphasize eco-friendly practices and digital technologies, thereby fostering a mindset geared towards sustainable and technologically advanced engineering solutions.

| <b>CDIO Phase</b> | <b>Integration of ENCORE</b>                                              | <b>Benefits</b>                                                 | <b>Potential Challenges</b>                       |
|-------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------|---------------------------------------------------|
| Conceive          | Providing OERs on green digital technologies and entrepreneurial thinking | Enriches conceptual learning with sustainability and innovation | Aligning resources with specific project concepts |
| Design            | Presenting green design principles and digital innovation strategies      | Encourages eco-friendly and technologically advanced solutions  | Ensuring the relevance and accuracy of content    |

|           |                                                                             |                                                                          |                                                             |
|-----------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------|-------------------------------------------------------------|
| Implement | Offering case studies on implementing green technologies and digital tools  | Bridges theory and practice in sustainable engineering                   | Tailoring examples to diverse student projects              |
| Operate   | Access to resources on sustainable operation and entrepreneurial management | Prepares students for operational challenges with a sustainability focus | Balancing operational, sustainability, and business aspects |

Table 1. Integration of ENCORE in CDIO Phases with a Focus on Green Digital and Entrepreneurial Skills

### ***Implement Phase***

In the 'Implement' phase, the focus shifts to the practical implementation of designed systems. Here, ENCORE's repository offers practical examples and case studies demonstrating the application of green technologies and digital tools in real-world engineering projects. This phase benefits significantly as students get to understand the challenges and methodologies involved in implementing sustainable and technologically driven designs.

### ***Operate Phase***

The 'Operate' phase revolves around the operation and maintenance of engineering systems. ENCORE's role in this phase is pivotal in providing resources that discuss sustainable operation practices, digital optimization of systems, and entrepreneurial management strategies. These resources prepare students to manage and operate engineering projects with a focus on longterm sustainability, digital efficiency, and innovative business models.

## **CONCLUSIONS**

The integration of the ENCORE approach within the CDIO framework marks a pivotal advancement in engineering education, addressing the pressing challenges of digitalization, environmental change, and economic shifts. This paper has detailed how ENCORE, leveraging OER and NLP, enriches each CDIO phase with green digital and entrepreneurial skills, enhancing the educational landscape for engineering students.

Looking ahead, the next phase of ENCORE's development is crucial. It involves the recruitment and training of higher education lecturers and vocational trainers in staff development activities centred around the ENCORE approach. This phase aims to enrol a diverse group of educators to test and maximize the application of ENCORE across various skill sets and course topics.

The focus will then shift to external development activities where these educators will be equipped to implement ENCORE in their teaching practices. The feedback from these activities is instrumental in refining the ENCORE methodology. Following this, a pilot phase will see the



ENCORE approach applied in real-world educational settings, providing a valuable opportunity to evaluate its effectiveness and impact.

The significance of testing ENCORE in engineering education, mainly through the lens of the CDIO framework, cannot be overstated. This setting offers an ideal testbed for assessing the adaptability and efficacy of the ENCORE approach. It promises to not only enhance the learning of critical skills but also provide insights into its scalability across educational contexts.

In summary, the future trajectory of ENCORE is set to make a substantial impact on engineering education. Through its upcoming phases, it will undergo rigorous testing and refinement, ensuring its role as a transformative tool in equipping future engineers with essential skills in an ever-evolving global landscape.

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# **III ENGINEERING EDUCATION RESEARCH**

# EXPERIENCES WITH SELF-MAPPING CURRICULUM AGILITY

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## ABSTRACT

Future-proof engineering curricula can cope with fast-changing circumstances, and the opportunities and threats these bring along in the context of the curriculum. Curriculum Agility (CA) is a concept aimed at helping higher education institutions analyse how responsive their programmes are to changes in society, industry, and student characteristics and needs. The CA model describes features needed to adapt curricular and organizational structures, learning content and outcomes, learning activities and pedagogies, staff development, and examination design in a timely and proactive manner. Based on the model, a CA Self-Mapping Protocol has been developed that aims to actively engage and simultaneously enable curriculum stakeholders in the self-mapping process. It was tested at five European universities and at different levels, i.e. university, department, and program level. Leading questions focused on the effects of the CA self-mapping process; and what that could mean for the set-up of the protocol. The aim of this paper is to present to what extent, and in which form, the self-mapping protocol, as a design-thinking, guided dialogue with multiple stakeholders, is valuable and feasible in different higher engineering education institutional contexts. All facilitators were able to adjust the protocol to local contexts. And although there were all kinds of differences (of use and process) between the institutes, what 'stands firmly' is the importance of the negotiating understanding of what CA is and what it means to the local context. The presence of the ten principles were instrumental to 'guarantee' that people were discussing and considering the themes that needed to be addressed.

## KEYWORDS

Curriculum Agility, Self-evaluation, Transformative Curriculum Change, Future-proof Engineering Education, Standards: 1-12

## **INTRODUCTION: MOTIVATION FOR MAPPING CURRICULUM AGILITY**

Curriculum Agility (CA) refers to the proactive responsiveness of the educational design and organisation of a higher education programme to changes in its context with high impact, such as technological developments, societal trends and disruptions, and the increasing diversity of the student body. The concept of CA has been developing since 2018 within the CDIO network in co-creation with members worldwide collaborating and co-creating in working group days, workshops, and roundtables (Brink et.al., 2023).

CA characteristics are flexible education, dynamic contents of learning, responsive organisation of the programme, and continuous (pedagogic) development of all involved academic staff. The ten principles to advance the CA of a programme are, in non-hierarchical order: (a) having an educational vision with agility in it, (b) involving stakeholders in the co-creation, including decision making, of the programme, (c) supporting pedagogic innovation and leadership through staff development, (d) assessing on holistic learning goals on programme level, (e) having dynamic content and flexible pedagogy in the programme and course design, (f) having flexible physical, digital and social learning spaces, (g) cultivating a change culture in the management approach, (h) reframing rules and legislation in its interpretation, (i) having a responsive administration governing the organisation, and (j) accommodating change implementation in the decision making processes. Throughout the iterative co-creation process of the CA model, the number of principles has grown from seven to eventually ten, and their grouping, wording, and descriptions have repeatedly been tweaked with consensus among the working group.

From the start, parallel to the process of establishing what CA beholds and how it can be accomplished, a way was sought to assess one's CA, much in line with the self-assessment on the CDIO standards, (Brink et. al., 2020). At the International CDIO Conference in Reykjavik, 2021, the CA working group started setting up a self-mapping protocol. It was agreed that the holistic character of the CA concept asked for a multi-level curriculum-stakeholder process, facilitating dialogue on a shared understanding and the narrative of the status quo of CA within the institution, followed by co-creation of plans and priorities. A toolkit was made to guide programme stakeholders and their facilitator(s) through the process.

## **AIM, RESEARCH APPROACH, AND STRUCTURE OF THE PAPER**

The aim of this paper is to present to what extent, and in which form the self-mapping protocol, as a design-thinking, guided dialogue with multiple stakeholders, is valuable and feasible in different higher engineering education institutional contexts, based on a pilot that has been done. In addition, the different insights and plans for action that result from the self-mapping process are described, as well as the impact the process had on its participants.

The paper briefly introduces the self-mapping protocol. The core of the paper presents five self-mapping pilots: the local motivation and objectives, the contextualised and tailored interpretation of the protocol, important results, and the experiences and reflections of the participants and facilitators. The next section synthesizes the main insights, on which the conclusion bases an indication of the value of self-mapping CA, recommendations for the self-mapping toolkit, and recommendations for the next steps of the CDIO CA workgroup.

## METHOD: THE SELF-MAPPING PROTOCOL OF CURRICULUM AGILITY

Five European universities tried out the CA Self-Mapping Protocol in one pre-pilot and four pilots: Eindhoven University of Technology at institutional level, Umeå University at faculty level (pre-pilot), Chalmers University of Technology at school level, Delft University of Technology at department level, and Turku University of Applied Sciences at programme level. The authors were the facilitators. The pre-pilot was executed in 2022 and the pilots in 2023. Preliminary results were discussed at the CA working group day at the International CDIO Conference in Trondheim in 2023.

The toolkit was a PowerPoint presentation with supportive materials included in the slides, some to be shown, others to be printed and worked with as templates during the interactive sessions. For the facilitator, there were hidden slides that gave supportive information, including facilitator's task slides, and instructions in the notes of each slide. Facilitators organised the CA self-mapping sessions, invited relevant participants, kept overview, and communicated the results within their organisation. The self-mapping protocol contained five main steps: Informing, Probing, Envisioning, Strategizing, and Prioritizing, each with their own goals, deliverables, and suggested approach, see Table 1.

Table 1: The Self-mapping Curriculum Agility protocol.

| ON THE 10 PRINCIPLES of Curriculum Agility (CA) |                     | Reflective Dialogue                                                                                      | Co-Creation                                                                 |
|-------------------------------------------------|---------------------|----------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| <b>Step 1</b>                                   | <b>Informing</b>    | Negotiating local interpretation of CA and its principles                                                | Shared Understanding                                                        |
| <b>Step 2</b>                                   | <b>Probing</b>      | Sharing single-level experiences and perceptions of strengths, weaknesses, obstacles, and enablers in CA | CA Narratives per principle of the present situation within the institution |
| <b>Step 3</b>                                   | <b>Envisioning</b>  | Imagining desirable curriculum designs 10 years from now                                                 | Future Scenarios of curriculum design and organisation with agility         |
| <b>Step 4</b>                                   | <b>Strategizing</b> | Finding agreement and grouping actions to increase CA                                                    | Strategic CA Plot                                                           |
| <b>Step 5</b>                                   | <b>Prioritizing</b> | Weighing actions in focus and direction on importance and timeline                                       | CA Transformation Plan                                                      |

The self-mapping protocol was flexible in its set-up, to enable universities in different local contexts to use it in a meaningful way. Therefore, variety in the self-mapping approach was stimulated and expected in the pilot and asked to describe by the facilitators afterwards.

## RESULTS: SELF-MAPPING PROCESS EXPERIENCES

The following subsections describe the pilot experiences on five aspects. In each institute, there were local objectives and motivations for doing the self-mapping (i). The protocol was tailored to local circumstances (ii) and different stakeholders (iii) were involved. There were various concrete outputs (iv) in each case. And reflections by the participants and/or the facilitators on CA and its (tailored) self-mapping process (v) were tracked.

## ***Eindhoven University of Technology – Institutional Level***

The self-mapping pilot at Eindhoven University of Technology (TU/e) was carried out in the context of the university-wide redesign of the bachelor curriculum in all engineering departments. After an evaluation of the engineering bachelor programs in 2019/2020, a curriculum transformation took place to align the programs with the TU/e vision on education and current developments. The redesign of the BC curriculum was chosen as it follows a developmental approach which is constructed throughout the years to achieve the education vision. Other characteristics of the redesign are the TU/e stakeholders' involvement, and the piloting phases to iteratively develop, test and adjust the programs with a departmental flavour.

As the TU/e CA experience focused on the redesign of the bachelor's degree programs university-wide, representatives from the different educational processes of the curriculum development were selected for the pilot. Individual sessions were organized by a facilitator with broad experience in curriculum development and innovations in teaching and learning. The pressure felt to finalize the design of the first year of the engineering study programs on time to be implemented from September 2024 onwards, together with the fact that many educational processes supporting the implementation of the new bachelor programs needed to be quickly aligned, caused less availability of the stakeholders to participate in several workshops following the CA protocol. Therefore, individual interviews with each participant were organized. Selection of stakeholders (N=11) was based on representatives from different processes, e.g. quality assurance, educational advisors support to teachers, information management systems, policy and regulations, academic teaching, management, etc. Individual interviews lasted a maximum of one hour and a half.

To set up the context for the analysis, participants were exposed to a general introduction of the CA elements as well as the 10 principles (Step 1), with the use of the toolkit. Likewise, a shared of comparisons between the CA model and the current experiences of the redesign of the bachelor curriculum (Step 2) facilitated a better understanding of the principles. For example, Principle 5 on decision-making was compared to current processes of educational committees at the departments to approve courses; Principle 8 related to learning spaces was compared with the university systems, tools and learning environments being currently updated to meet innovations in teaching and learning; or Principle 10 on stakeholders' involvement, similar to the co-determination processes at the university and the involvement mechanism of communicate to consult university employees. These comparisons supported participants to, consequently, visualize a desired curriculum and the processes for future and similar curriculum change and experiences (Step 3). Finally, future directions were formulated in the canvas by not only prioritizing the desired changes, but also formulating actions that may foster a more agile curriculum transformation (Step 5). As interviews were individually conducted no co-creation of a joint strategic plan was formulated, and therefore, Step 4, was missing in this process.

The self-mapping process helped participants to reflect upon the curriculum process which has enriched the understanding of what agility is and how it can be applied in a curriculum transformation. There is no doubt that the CA model is insightful to strategically visualize the improvement of processes that lead to educational reform in a university. In addition, the experience is promising to create ownership of the process, reinforcing the involvement of key participants, making changes successful. Participants appreciated the value of the CA self-mapping process, and in particular, the tool that serve as a guideline to visualize the different elements and processes involved in a curriculum redesign. Although the participants were part of individual interviews, they considered that it would be interesting to have a joint session to



convey on main directions of future actions. Likewise, the facilitated valued the CA model as it provides opportunities for dialogue with all stakeholders and layers of the university.

### ***Umeå University – Faculty Level***

The faculty of Science and Technology at Umeå University has been a CDIO member for over twenty years and has fully integrated the CDIO standards in its quality system. Programmes and courses are improved, tweaked, and sometimes newly designed in accordance. The CA self-mapping was done as a pre-pilot at the faculty, with five stakeholders of the Interaction and Design programme from faculty management, department management, program management and lecturer level. When asked, participants indicated they engaged to learn about the CA concept and how the faculty was doing, be inspired to get more CA, and to help develop CA from academic motivations.

Four steps of the protocol were done January and May 2022, one step each month. They were prepared, planned, and executed by a facilitator, who was involved in the CA project from the start and thus had ample pre-knowledge about CA. After the pre-pilot, facilitator-instructions were added to the protocol so any facilitator could do the task.

In Step 1: Informing, each participant took part in a semi-structured, 60-90-minute interview. The participants read and responded to each principle in dialogue with the facilitator, based on four questions: Is and should this be strategically prioritised? Do you have this on your level? How is this at other levels within the faculty? What are obstacles and facilitators for this? The interviews were recorded, transcribed, and put together per principle to form narratives for Step 2: Probing.

The four perspectives of teachers, and faculty, department, and programme management, were categorized in topics and clustered. These narratives showed the similarities and discrepancies between the perceptions of the respondents on each principle. For instance, under Continuous Staff Development, the faculty management indicated all the room, resources, and stimulation there was for teachers to develop their teaching competence, initiating pedagogic innovation, and taking part in engineering education research. At teacher level, the eager ones were seen to find their way to these resources. But the department saw all too many teachers not willing to participate in such endeavours, also in other departments. However, under Programme Design, all agreed on the value of the electives and projects allowing for more dynamic content, and the cross-disciplinary learning opportunities in the year-4 design-build-test course. The participants edited the narratives, at the same time getting a peek into the others' perceptions.

Step 3, was done by the two programme managers, dreaming about the programme in ten years. Then, CA measures needed to get there were back-casted. These were added in Step 4: Strategizing. First, each participant was asked individually to prioritize CA measures based on the CA Narratives, the dream scenarios, and personal reflection three months into the trajectory. These measures were mapped on importance (must-have, should-have, would-like-to-have), and implementation time (short-term, long-term, probably not going to happen). All participants met in a final session. They discussed the overlap and differences in their views, rearranged measures, and dot-voted on the most important ones together. They spotlighted working on the perception that it was difficult if not impossible to change a course, getting more academics to do staff development on teaching, and getting the focus of course and programme renewal directed at the students' learning (throughout the programme), instead of the teachers' teaching.

The pre-pilot evaluation showed that the concept of CA had been new to the participants but associated with CDIO and educational development directly. The expectations of the participants were met and exceeded, and all principles were deemed meaningful and important. The collaborative process was appreciated, especially being able to first formulate one's own thoughts, then learn about other people's perceptions, and so come closer to significant issues. However, the facilitator had learned that Steps 1 and 2 had taken over 40 hours, which was undesirable.

### ***Chalmers University of Technology – School Level***

Education at Chalmers is organized in Educational Schools, and the self-mapping pilot was carried out at the School of MATS (Mechanical engineering, Automation and mechatronics, Industrial design engineering and Marine engineering and Shipping). It suited the school very well to conduct the CA self-mapping pilot since several of the programme heads were new and needed to get to know their programmes well to identify strengths, weaknesses, and development opportunities. Furthermore, the rapid technological development and demands from industry, society, and students to act more swiftly motivated an examination of how agile the programmes are. As Chalmers recently formulated a new vision for the university, with a strong focus on excellence in research, education, and innovation, this worked as an additional catalyst for undertaking the CA mapping.

The mapping process was designed as a full-day workshop with eight programme heads. The school management was also taking part in the workshop with three participants: the dean, the coordinator, and the administrative support. During the workshop, steps 2-4 in the self-mapping process were covered. The first step was initiated by the dean at a regular school management meeting about a week before the workshop. During that meeting, the dean (who was also a co-facilitator and participant in the workshop) informed the participants about CA and the mapping process. The actual workshop the following week was led by a facilitator with a long experience from the CA project. After a concise introduction by the dean to the remaining steps of the CA self-mapping process, the dean joined to take part in the mapping process as a participant. Then, all the participants were divided into four teams. The teams were formed according to the different roles of the participants, with three teams of programme heads and one team consisting of the management group. The teams with the programme heads were based on "adjacency", that is, similarities in fields of study.

Throughout the workshop, the steps were introduced and then followed by the work of the teams on each step before moving on to the next step in the process. The participants completed the steps using post-it notes and visualizing the output on paper. The documentation from the steps became somewhat fragmented when the facilitator collected the materials from the teams, as the different participants chose to record the steps in slightly different ways. It was also difficult for the facilitator to summarize each step since time between each step was restricted. Despite the challenges with logistics and clear summaries of each step, the outcome of the workshop was positive. All participants expressed that the mapping process was intuitive and useful for evaluating their programme's curriculum design as well as envisioning new possibilities, not least in the light of a new overall vision for Chalmers. Particularly the program heads that were new in their positions, expressed that the mapping process was very useful for a broader, as well as deeper, understanding of the programmes. In addition, the workshop yielded valuable results, encompassing narratives, identified obstacles, and enablers linked to various CA principles, along with potential areas for improvement. These findings are currently being employed in a broader programme reform initiative that engages teachers, students, and external stakeholders.

The workshop format aided the mapping process, but maintaining a consistent pace proved challenging for participants. Consequently, there was overlap between steps, leading to the merger of steps 2 and 3. Step 4, strategizing, marked the workshop's conclusion, while step 5 seamlessly integrated into ongoing program development. Participants found the workshop valuable and productive, yet facilitators encountered challenges in time management, collecting, and summarizing output from various steps. Based on this experience, a digital format for the participants to enter the data from the different steps would have made collecting and comparing the results easier.

### ***Delft University of Technology – Departmental Level***

The Department of Urbanism in Delft has a Daily Board Education (DBE) in which all its six research groups are represented by their section education coordinators. Additionally, this DBE consists of a chairperson, the Head of the department, the departmental manager, and secretarial support, and is visited regularly by degree program leaders. It monitors all kinds of education quality, staff deployment, and education organization issues. Two CA facilitators together prepared and documented the self-mapping process for the Urbanism department. They perceived that within the department, there is a shared, but implicit idea that its CA could be improved.

First, several pre-selected colleagues in four categories were invited for four separate 1.5hrs sessions: [i] tenured scientific staff (3 persons), [ii] departmental management (3 persons), [iii] junior teachers/Ph.D. candidates/M.Sc. students (2 persons), and [iv] colleagues who are committee members (board of studies, board of examination) and educational support staff (4 persons). In those four sessions, a shortened slideshow was used to introduce (step of Informing) the CA concept, model (including the 10 principles), and the process. Then people were asked to individually develop their narratives in 20-mins based on the ten principles that we printed out for everybody as 'puzzle pieces'. People were then asked to pitch their narrative (step of Probing). Photos were made of all the puzzles. The facilitators made personal notes of what people were emphasizing. Then for each principle, a statement or position was plenary developed (step of Probing and partly Envisioning). At the end of the session, people were asked to share their experiences and feelings about this workshop.

Secondly, the facilitators together developed a 500-word departmental CA narrative, based on the workshop results and own – as departmental education leader and M.Sc. program leader – view on things (step of Envisioning). The main building blocks of this departmental narrative were the conflicting perceptions of the colleagues on almost all principles. Thirdly, this narrative was shared with all DBE members (11 persons), and further discussed and reflected upon in a 2hrs workshop session (steps of Strategizing and partly Prioritising; 9 persons) based on two questions:

- What is the desired direction of improving our CA? What is a need-to-have and what is a nice-to-have?
- Do you see the first concrete priorities, actions, or steps that you would like to propose?

Many DBE members were on the one hand surprised by the shared narrative but agreed with it anyway as a realistic snapshot of our department. Many ideas popped up and it was decided to discuss the CA of our department twice a year in a DBE meeting based on the updated document the facilitators made (shared narrative + strategies).

Several responses and reflections to the CA model and CA self-mapping process stood out:

- The model and principles were very helpful for everybody building their own narrative. Many people felt that there was substantial thinking and knowledgeability behind the materials.
- Making explicit your view and perception of things was appreciated a lot. The 'puzzle exercise' helped people to strengthen their vision (they said themselves). Participants were happy that there was/is no good or bad in the individual self-mapping. Your perception is just what it is.
- Participants were happy to share and discuss their individual narratives but also to hear and comment on the ones of others. It simply gave them a more in-depth understanding of the issues at hand and their complexities.
- Nobody had suggestions for additional principles. These ten were doing their job properly.

### ***Turku University of Applied Sciences – Programme Level***

The CA self-mapping piloting at Turku University of Applied Sciences (Turku UAS) was carried out in the unit of Chemical industry in the faculty of Engineering and business. At Turku UAS, CDIO based pedagogy has been applied for 5-10 years depending on the unit and it has been seen as a solution for more fluent combination of education and research, development and innovation activities that also eases teachers' workload. Turku UAS is currently undergoing a curriculum reform, which will take place from August 2024. Thus, CA mapping pilot was seen as a good opportunity to map the status quo. We were eager to explore in what areas we have succeed, but also to point out the development needs. The general idea was to keep it simple for understanding the value of the pilot at first. Therefore, CA self-mapping pilot was implemented with a small team at the programme level. The group included 4 curriculum designers (Degree programme leaders), Head of education and research, and facilitator (Research team leader). At this point no other stakeholders were invited to the piloting. The piloting was carried out in 4 sessions within 7 weeks in April and May 2023. Steps 1 and 2 were combined, but otherwise the piloting was carried out according to the pilot instructions. The first session was longer (2,5 hours), and all the other sessions were 2 hours long. There were about two weeks between the sessions.

All participants were aware of the self-mapping process and the principles before the first session. Later, the participants prepared themselves in advance for the sessions by going through the material generated during previous session. During the first session, the pilot group went through each principle by discussing what it meant and what thoughts they had of the principle, after which they wrote down their own narratives into a template in Forms. This way, a common understanding of the principles was achieved. Later, the facilitator collected the narratives into a PowerPoint presentation and delivered it to participants for reading. For the sessions 3 to 5, post-it boards were built into a Mural board, where all the participants had access. During the discussion, either the participants themselves or the facilitator wrote down the ideas into Mural. These post-it notes were then further processed during the process.

As outcome, we achieved an understanding of our status quo and positive feeling that we can affect our work. We have freedom to manage our work and the organization is not limiting our CA. We also found ourselves to be proud of our multidisciplinary courses with holistic goals, agile course design and modern learning spaces. The area of development was lack of time. As our curriculum was already in a reform process, the new curriculum was listed as a direct must-have outcome. Other must-have outcomes were all dealing with communication at the short-term level.

The CA self-mapping pilot was perceived as interesting and meaningful. However, the biggest advantage of the sessions was considered to be the opportunity to discuss, as in the unit, there

is not much time left for dialogue in everyday life. The conversation was active, and it was the facilitator's job to make sure that the topics were recorded, and from time to time to get the conversation back on track. Finally, a couple of improvements to be carried out on a quick schedule were selected, also implementers were selected from the group. Based on the feedback, the participants were satisfied with the tools and the way the sessions were organized.

## **SYNTHESIS**

The CA Self-Mapping Protocol was meant to guide and support facilitators, while leaving them room to adjust working methods in each step to their context, the desired resolution of the mapping, and available resources. With five different resolutions of mapping in the pilot, being university, faculty, school, department, and programme level, both similarities and differences in execution show.

From Umeå it became clear that transcribing and coding interviews was too time-consuming, and the narratives could be better generated in collaborative sessions in the protocol. Also, it was nice to have a strategic CA measures map, but to secure a follow-up an action plan needed to be formulated as well. At TU/e, the interviews were also held individually, as well as follow-up steps. Reason for this was that the stakeholders could not participate in several workshops at the same time. Although this set-up was still very insightful, a joint formulation of strategy and action was lacking. Chalmers had the opportunity to introduce CA during a management meeting when all were already present, bypassing TU/e's problem. They chose to have all the other steps in one day with the whole group present. The interactions gave participants valuable insights, but there was not enough time for the last steps. At TU Delft, an interactive exercise done during the CDIO conference working group day inspired to organize step 2 likewise as a workshop series for small groups. Here, participants not only developed their personal narratives but were also able to present and discuss them with colleagues. Turku was well on their way to design a new program and used the self-mapping for evaluating their status quo. Combining steps 1 and 2 reduced the number of sessions which made it easier for all to participate the whole process. Using digital tools for the templates in the toolkit helped them a lot while reporting the results. And their pilot showed that different language versions might be desirable, as talking about complex issues in a language different from the mother tongue sometimes caused more confusion than shared understanding.

Looking at the nature of the local adjustments to the protocol, what 'stands firmly' in the protocol for all as valuable is the importance of negotiating a local understanding of what CA means, whether this happens in Step 1 or 2. Second, all ten principles and their descriptions were helpful for both facilitator and participant. They were also instrumental to 'guarantee' that people were discussing and considering the themes that needed to be addressed. Even when participants felt they had no control over some of the educational or organisational principles, talking about the perceptions with those who do, gave new insights on both sides. Third, all five steps of the protocol stood firmly in being regarded as valuable. It became clear that not all steps can be done in one day or one session, as lean as that would be, and it is hard to get everybody in the same room at the same time. But the pilots that did not make it all the way to Step 5 noted that this stands in the way of a structural work continuation on the measures and plans. Fourth, the multi-stakeholder, co-creation approach had the effect that dialogue happened which normally didn't take place, either for lack of time or for lack of occasion in the existing operationalisation of the curriculum organisation. And this dialogue was much appreciated.

## CONCLUSIONS AND STEPS FORWARD

### ***Lessons learned for CA and its Self-Mapping Protocol***

Curriculum change is *daily business* in education nowadays. Universities are challenged with rapid technological and societal developments, industry requirements, and students' changing characteristics that need to be incorporated in study programmes. This requires a holistic or integrated approach working from a joint educational vision in joint ownership. The CA Self-Mapping Protocol invites to think critically and together with other stakeholders about the future of a programme and the (re)design of its curriculum. From the pilot, we have learned that participants consider CA an intelligent concept and its model complete and meaningful. That (practical) expertise was at the base of the model became evident in recognition of the principles, and it made it easy to trust the self-mapping process. The inter-level collaboration was appreciated and once everyone was together in the room, the protocol was experienced as smooth and productive.

For the facilitators it was challenging to get everybody in the same room at the same time when the protocol asked for that. This was one of the main reasons for local variations of the protocol. It makes planning ahead extra important. Opportunities of existing meetings in which the self-mapping activities can take place are worth using. The facilitators were aware that their participants were curious and willing to be part of the pilot. Hence there was less resistance to overcome, which in a non-pilot situation might be different. It's difficult to decide which participants best to invite. On the one hand, the ones who are pedagogically involved are most willing to put time and effort into it, but the ones who don't see the value per se are also of interest to be heard in the self-mapping. In any way, getting the different level stakeholders involved is important for a fruitful self-mapping. Solutions were found in breaking sessions up in smaller groups, leading to more work for the facilitator, but better coverage of the stakeholders. Sharing the burden with two facilitators can be a solution to that problem. Another variation to the protocol to consider is combining steps: Step 1 and 2 in one session, and Step 3, 4 and 5 in the next; or three sessions, a short Step1, a long step 2, 3 and 4, and a short Step 5; or combining Steps 4 and 5 to use the enthusiasm raised during strategizing directly to think implementation. But the larger the groups, the harder it might become to combine different steps.

Beyond the Self-Mapping, a challenge was seen in what happens afterwards. Who takes over and sees the strategies, priorities, and action plan through? In the pilot, the intention with which the self-mapping was done differed considerably, and hence also the follow-up. It would be good to add follow-up of the action plan in the toolkit's workshop templates.

### ***Lessons learned for the Toolkit and Facilitator***

The facilitators agreed that the toolkit, the PowerPoint materials, helped to get the flow up right away during the sessions. The materials offered were deemed important in facilitating dialogue. The liberties in approaching the protocol and seeing what works best for each situation were highly regarded and necessary. In the toolkit, multiple variants could be mentioned to give future facilitators guidance in the possibilities and their consequences.

Of course, a facilitator must know something about CA to feel comfortable with the role and be able to answer participants' questions. At the time of writing, a CA Quick Scan is being developed, which will help facilitators with this on top of the toolkit material. However, the protocol in Step 1 and 2 also leaves room for session designs in which participants together

find out the answers to unclarities, and thus only increasing their shared understanding and detailing their narratives. It was also discussed that documentation on CA could be made to send around beforehand, but the pilot facilitators felt participants hardly had enough time to come to the sessions, let alone prepare in advance. Homework in between the steps is another option to give participants the opportunity to be involved and feel their voices heard.

Another idea is to make a digital interactive version of the toolkit, in which all the steps can be done online (both synchronous or asynchronous). Some universities have locations far spread out and are destined to work online for such endeavours. Additionally, the difficulty of getting busy colleagues in the same room at the same time can be overcome by working digitally in an asynchronous way. Special attention would have to be paid to guaranteeing true dialogue in this set-up, for instance by synchronous online meetings in the first and last steps.

The recommendations from this pilot will be discussed with the CA working group and integrated into the design of the protocol and toolkit. A next round of Self-Mapping universities is already forming, so they can work with improved materials. And the materials are aimed to become available to all CDIO members as well.

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# **BOOSTING PERFORMANCE WITH AI-POWERED ADAPTIVE LEARNING**

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## **ABSTRACT**

The diversity of today's learners, with varying backgrounds and preferences, calls for a personalised approach to education. Traditional teaching methods disregard individual learning styles, pace, and strengths. This can cause some learners to fall behind or lose interest. Thus, adaptive learning through personalised and inclusive teaching strategies are essential for effective learning. Adaptive learning is a relatively new field, but it has the potential to revolutionise education by helping learners achieve their full potential. This paper explores the use of Artificial Intelligence (AI) - powered adaptive learning in engineering mathematics education. AI-powered adaptive learning uses machine learning to analyse learner data to create personalised learning roadmaps with customised content, targeted focus on specific areas and frequent practice for each learner. This approach empowers learners to receive immediate feedback and focus on their specific needs, leading to improved learning outcomes. At the end of this paper, the recommendations on how to improve AI accuracy for delivering materials and assessments will be discussed.

## **KEYWORDS**

adaptive learning, personalised learning, self-learning, sustainable engineering education, digital transformation in engineering education, CDIO standards 7, 11

## **INTRODUCTION**

A review of the literature shows that traditional classroom learning is not always ideal, as learners have different learning pace and needs (Kaminskiene & DeUrraza, 2020). At the School of Engineering, Nanyang Polytechnic, we have a diverse student population with a wide range of educational backgrounds: secondary, pre-university, vocational and technical education graduates, and adult learners from the industry. Teaching at the right pace for all learners is challenging, especially with average class size of twenty-two learners, it can be difficult to give individual attention to each learner (Ministry of Education, 2020). Additionally, structured curricula and lesson times limit learners' ability to reflect, internalise, and apply their learning (Kapp, 2016).

There is a growing demand for innovative and effective approaches to address diversity in the classroom and improve learning outcomes. Adaptive learning is one such approach. It utilises technology to monitor learner's progress and use data to modify teaching content based on individual needs (Becker et al., 2018).

To achieve this, real-time assessment, data analysis, and machine learning are used to continuously adjust the learning path based on learner feedback (Baker, 2012). Artificial Intelligence (AI) -driven assessments provide valuable feedback on learner performance and progress (Chassignol et al., 2018). Based on the 'report card', adaptive learning tools generate personalised study paths for each learner, recommending the most relevant materials to bridge gaps in knowledge and focus on areas for improvement.

Brightspace LeaP is an adaptive learning technology that allows instructors to create knowledge maps and adaptive pathways for each learner (Schaffhauser, 2014). This is made possible by AI analytics that monitor learner progress and automatically adjust the learning path accordingly. This personalised approach can help learners achieve better outcomes and improve their overall learning experience. However, this technology is relatively new and more research is needed to fully understand the impact of adaptive learning in polytechnic education.

## **APPROACH AND IMPLEMENTATION**

In April 2022, Nanyang Polytechnic adopted Brightspace, a learning management system (LMS) that comes with intelligent agents that allow instructors to provide personalised learning paths for learners. The Brightspace adaptive learning system considers learning materials, learning objectives, learner data, and instructor input to create personalised learning paths for each learner as illustrated in Figure 1. The system also includes practice questions, recommended reading, and feedback mechanisms to help learners progress.

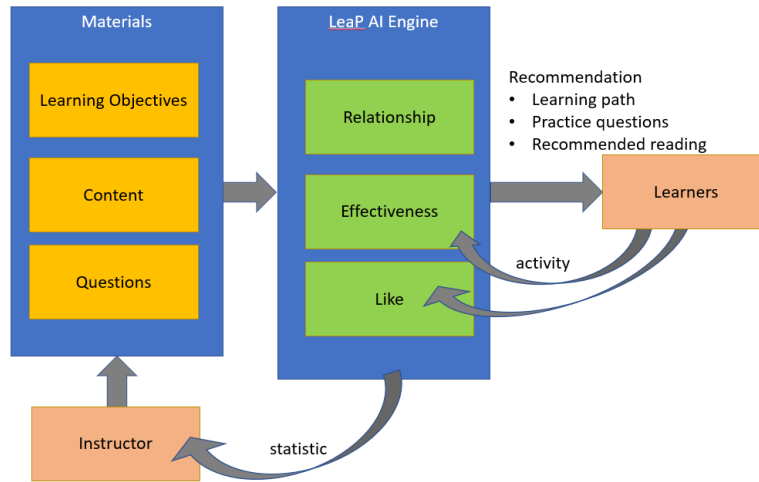


Figure 1. Adaptive Learning AI

The approach to develop the adaptive learning using Brightspace is as follows:

1. The instructor is to define the learning objectives to track the knowledge that learners acquire in the learning, as shown in Table 1.

Table 1. Define Learning Objectives

| TID | Parent ID | Title                    | Description                            | Leaf? |
|-----|-----------|--------------------------|----------------------------------------|-------|
| 1   | 0         | Calculus                 | Calculus                               |       |
| 2   | 1         | Multi-variable Functions | Differentiate multi-variable functions |       |
| 3   | 2         | Partial Derivatives      | Partial Derivatives                    | y     |
| 4   | 2         | Chain Rule               | Chain Rule                             | y     |
| 5   | 1         | Integration by Parts     | Integration by Parts                   |       |
| 6   | 5         | Formula                  | Integration by Parts Formula           | y     |
| 7   | 5         | DI                       | DI method                              | y     |
| 8   | 5         | DD                       | DD method                              | y     |

2. Using Brightspace’s AI suite, the adaptive learning engine semantically maps the content materials and questions in the question bank to learning objectives, as shown in Figure 2.

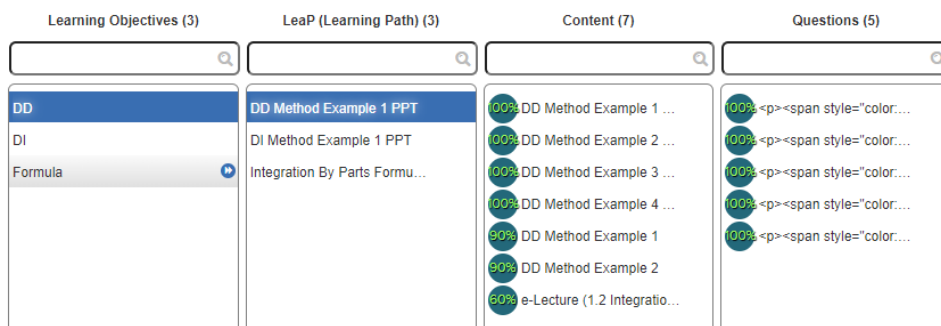


Figure 2. Automatic mapping of content and questions to learning objectives using AI

3. Learners start the adaptive learning program by taking a diagnostic test, as illustrated in Figure 3. The AI then filters out content related to learning objectives that the learner has already mastered, so that the learner can focus on their specific knowledge gaps.

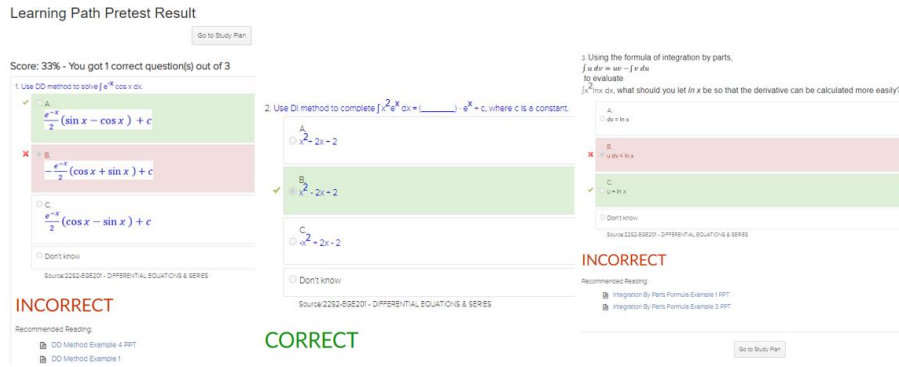


Figure 3. Diagnostic Test

4. The adaptive engine generates personalised learning plan (learning path) for each learner based on the success rate of learners answering the test questions. Figure 4 shows an example of the generated learning path which recommends study materials based on relevance to the learning objectives, effectiveness in helping the learner answer questions correctly, and the number of "likes" awarded by other learners.



Figure 4. Personalised Learning Plan

5. Learners can access additional recommended readings and practice questions, as shown in Figure 5, to deepen their understanding. The adaptive learning engine guides them towards mastery of the material through a cyclical process of "learning, testing and reinforcement".

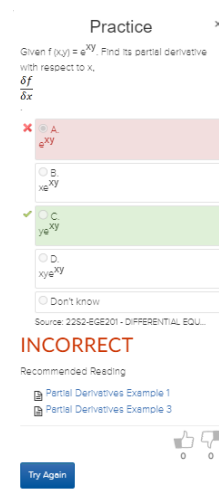


Figure 5. Practice Questions

## **RESEARCH AIM**

The aims of this project are:

1. To use AI technology tool to customise and personalise targeted learning plan for learners.
2. For learners to assess their learning gaps and focus their energies on those areas that need help.

## **RESEARCH QUESTIONS**

The research questions are as follows:

1. How much does the use of adaptive learning technology improve learners' performance in differential equation topics?
2. What are the perceptions of learners about the usefulness, satisfaction, and ease of use of the adaptive learning tool?

## **PARTICIPANTS**

This study involved 86 second-year learners, aged 18 to 25, from the Diploma in Electronic & Computer Engineering (DECE). The average class size was 22, with 7% of the participants repeating the module and 6% having special learning needs. The learners' GPA ranged from 0.74 to 3.91, representing a diverse range of academic abilities.

## **METHODOLOGY**

This study used a pre-post test within group design to evaluate the impact of an adaptive learning tool on learners' performance in two engineering mathematics topics in a mathematic module, Differential Equations and Series.

The control group consists of learners who attended the lectures and tutorials but did not use the adaptive learning tool. They attended lectures and tutorials, followed by a pre-test on the topic covered. They used lecture notes and tutorial materials to study for the test.

The experimental group, which consists of the same group of learners, was introduced to the adaptive learning tool and given a week to use it. A post-test was then administered to assess their performance.

This process was repeated for the second topic to observe any differences in results.

At the end of the study, learners completed a survey to gather their perceptions of the usefulness, satisfaction, and ease of use of adaptive learning tool using the USE survey instrument. The questionnaire items are listed in Table 2.

Table 2 USE Questionnaire Items

| Usefulness                                                                                                                                                                                                                                                                                                   | Satisfaction                                                                                                                      | Ease of Use                                                                                       |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>• Adaptive Learning identifies my gaps and helps me reinforce my learning.</li> <li>• Adaptive Learning helps me to understand and apply the concepts.</li> <li>• I prefer individualised learning paths and focus remedial over the traditional approach.</li> </ul> | <ul style="list-style-type: none"> <li>• I feel more confident and motivated.</li> <li>• I wish it covers more topics.</li> </ul> | <ul style="list-style-type: none"> <li>• It is easy to use.</li> <li>• It is reliable.</li> </ul> |

## RESULTS AND DISCUSSION

Data analysis as shown in Table 3, revealed that adaptive learning improved learning outcomes, with average scores increasing by 16%, passing rate by 20%, and more learners scoring grade B and above. This demonstrates that adaptive learning leads to better performance for learners.

More significantly, learners who scored less than 50% in the pre-test improved their scores by an average of 35.4%. This shows that adaptive learning can help low-performing learners close the performance gap with high-performing learners.

T-tests confirmed a significant difference between pre-test and post-test performance for both topics, with p-values of 0.0011 and 0.0012, respectively. This indicates that adaptive learning is effective in improving learners' performance in both topics.

Table 3. Data Analysis (T-test)

| Topic   | Tests     | No of Students | Mean  | Pooled Std Dev | t-value | p-value |
|---------|-----------|----------------|-------|----------------|---------|---------|
| Topic 1 | Pre-test  | 77             | 56.48 | 35.5           | 3.12    | 0.0011  |
|         | Post Test | 77             | 74.31 |                |         |         |
| Topic 2 | Pre-test  | 74             | 49.04 | 28.2           | 3.10    | 0.0012  |
|         | Post Test | 74             | 63.52 |                |         |         |

Figure 6 shows the results from a survey conducted at the end of the study to gather the learners' perceptions of the usefulness, satisfaction, ease of learning and ease of use of Brightspace Leap. Learners found adaptive learning useful and easy to use. Over 95% agreed that it helped them understand concepts and apply them. They found learning simpler, easier to understand and more appealing than the traditional learning approaches.

Learners appreciate the immediate feedback that the adaptive tool provides, which helped them identify their knowledge gaps and reinforce their learning independently. They also liked being able to focus on the most effective materials for each learning objective, which helped them clarify uncertainties and build confidence.

As a result, learners felt more confident and motivated to continue their learning journey. More than 80% of the learners preferred individual learning paths and focused remediation over the traditional one-size-fits-all approach. The word cloud in Figure 7 suggests that most learners find adaptive learning helpful, effective, and useful.

Despite the limited scope of this study, which only piloted two topics, learners expressed a desire for adaptive learning to be extended to cover more topics. This feedback suggests that adaptive learning can be a valuable and effective tool for enhancing the learning experience. The results of this research provide evidence in support to the use of adaptive learning in education.

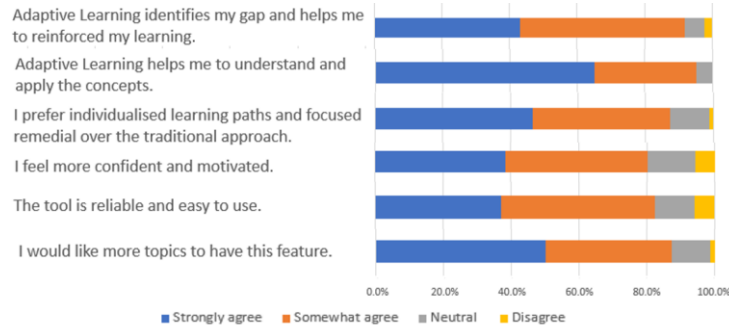


Figure 6. Survey Results



Figure 7. Word cloud on how the learners feel about adaptive learning

Another important aspect of adaptive learning is data analysis. This involves using the data from learners’ performance and interactions with the system to identify patterns and trends. This information can then be used to adjust the learning for individual learners, or to identify areas where the curriculum needs to be improved.

Adaptive learning also offers advantages from the teacher's perspective. By generating learning analytics, Brightspace provides valuable feedback that allows teachers to make decisions about their teaching strategies.

Brightspace provides teachers with an activity report (as shown in Figure 8) that displays the viewer rate of each learning objective. A higher viewer rate for a specific learning objective suggests that most learners may be finding that learning objective challenging and may benefit from additional support or clarification. The teacher can then allocate more time during face-to-face lessons to clarify these concepts.

| Learning Objective                       | Path Viewed | Supplemental Viewed | Recommend Reading Views | Question Remediation Views | Time On Page | Last Accessed        |
|------------------------------------------|-------------|---------------------|-------------------------|----------------------------|--------------|----------------------|
| Chain Rule                               | 210         | 41                  | 2                       | 32                         | 1.17:19:58   | 11/6/2022 5:18:19 AM |
| Partial Derivatives                      | 78          | 19                  | 7                       | 21                         | 16:28:45     | 11/6/2022 4:34:18 AM |
| View all Activity for "Topic 1.1 Leap 2" | 288         | 60                  | 9                       | 53                         | 2.09:48:43   | 11/6/2022 5:18:19 AM |

Figure 8. Activity Report

Brightspace also provides teachers with detailed information on individual learners' progress towards the learning objectives, enabling them to track each learner's performance and monitor the materials they have accessed.

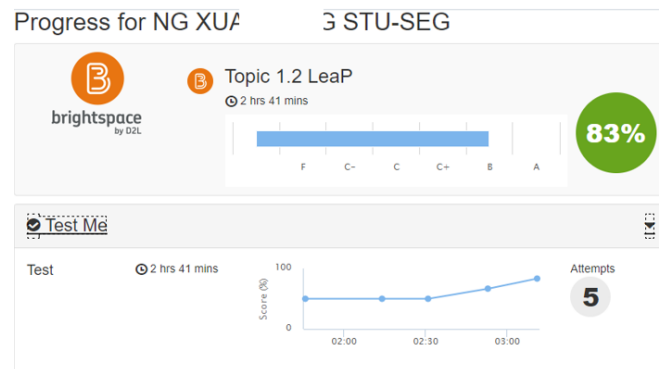


Figure 9. Learner's Progress Report



Figure 10. Learner's Viewing History

By identifying learners who have not made sufficient progress, teachers can provide targeted interventions and support, enabling them to achieve better learning outcomes. For example, teachers could arrange for struggling learners to attend peer tutoring or face-to-face supplementary lessons that target specific areas of difficulty. By leveraging the data generated by Brightspace, teachers can take proactive measures to help these students achieve their learning goals.

Additionally, Brightspace's ability to filter data by class allows teachers to identify the class learning profile and customise their classroom management techniques to better support their learners.

## CHALLENGES AND RECOMMENDATIONS

### **Challenge 1: The Need to Create More Contents for AI-Enabled Adaptive Learning**

To implement adaptive learning using Brightspace LeaP, instructors must create sufficient learning content and beef up question banks according to the learning objectives defined. This will allow the AI engine to generate adaptive learning paths with accurate materials.

We curated and adapted the existing content sources such as lecture notes and online resources, ensuring the alignment with specific learning objectives. The resources were chunked into bite-size and made into various formats, including videos, text, audio, and



animations, to meet diverse learning needs. All materials were strategically tagged for machine learning. However, this process can be time-consuming, so it is recommended to start small by implementing adaptive learning on a topical basis.

A comprehensive question bank that encompasses a wide range of question types and difficulty levels was carefully crafted with relevant keywords to enable the AI engine to accurately assess student understanding and identify their knowledge gaps. To beef-up the question bank, high-quality questions were created to align with specific learning objectives. Existing question banks were aggregated and vetted for quality and relevance.

### ***Challenge 2: Addressing the Accuracy of the AI Model***

AI-enabled adaptive learning systems require a robust AI engine capable of accurately interpreting student responses, identifying knowledge gaps, and recommending personalised learning paths.

We tackled the challenge of improving AI accuracy by capturing a comprehensive dataset of student interactions through assessments, practice exercises, and self-paced activities. This improves the AI engine's predictive capabilities for precise recommendations of study materials and assessments to pitch the knowledge gaps. Iterative evaluation of study materials driven by their effectiveness in helping the learners improve, along with the number of "likes" awarded by the other learners form a feedback loop, contributing to continuous optimisation of the AI's performance.

### ***Challenge 3: Use of Relatively New Technology for Education***

Integrating adaptive learning into the polytechnic's curriculum marked a departure from conventional methods. The risk involved adopting a relatively new technology, untested in the polytechnic educational landscape, and the uncertainties about its reliability, effectiveness, and suitability for mathematics instruction.

We worked closely with the Center for Teaching and Learning Development (CTLTD) at Nanyang Polytechnic and the Brightspace developer for technical support. The pilot program involving 86 learners provided valuable hands-on experience, enabling the evaluation of the technology's functionality and effectiveness in an authentic learning environment. The approach not only addressed the uncertainties but also laid the foundation for refining the adaptive learning platform.

To support other educators in embracing adaptive learning, we collaborated with CTLTD to organise trainings for teachers. We also shared our experiences and lessons learned through conferences and webinars with other institutions of higher learning and communities to promote personalised learning.

## **CONCLUSIONS**

Adaptive learning benefits both learners and educators.

For learners, adaptive learning improves understanding, engagement, and performance. It is also time-efficient, as learners only focus on what they need to learn. Both statistical and survey results show that adaptive learning is preferred over the traditional one-size-fits-all approach.

For educators, adaptive learning improves teaching effectiveness and identifies areas for curriculum improvement. It is a well-received tool that can be used in most courses.

Adaptive learning is a powerful learner-centric tool that revolutionises the teaching and learning experience. The encouraging results of this investigation encourage educators to use adaptive learning to support learning.

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# IMMERSIVE DIGITAL TWINS OF AN INDUSTRIAL FORGE ENGINEERING EDUCATION

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## ABSTRACT

The rapid and relentless pace of technological advancement over recent years has had a profound impact on the realm of education. This dynamic transformation has paved the way for a host of new possibilities and innovations that are reshaping the educational landscape. One of the most noteworthy developments within this technological revolution is the advent of virtual and augmented realities. These immersive technologies have become pivotal in shaping the evolution of educational tools and systems across universities worldwide. For examples of this phenomenon, one can refer to recent works such as Sandyk et al. (2023) and Kontio et al. (2023). The "JENII project" is an example of initiative in the sphere of immersive education, which is being spearheaded by the Arts et Metiers Institute of Technology. This project is set on a course to revolutionize engineering education by designing a suite of immersive and interactive digital twins. While Engineering Learning Workplaces are not physically present, the immersion enabled by the technology, when coupled with a machine's digital twin, closely replicates the genuine interaction an engineering student would encounter in an industrial environment. Thus, within the framework of the Conceive-Design-Implement-Operate (CDIO) approach, these immersive digital twins are envisioned as virtual counterparts to the workplaces described in Standard 6. However, immersive digital twins are not static; instead, they offer the prospect of continuous optimization to provide engineering students with a dynamic learning experience. A important attribute of these digital twins is their potential to catalyze Active Learning, a fundamental component of CDIO (Standard 8). They offer students unfettered access to a set of realistic exercises, during both classroom sessions and independent study. These exercises are meticulously designed to simulate actions that students would undertake on actual machines, fostering a hands-on learning environment. What sets these digital twins apart is their ability to allow students to repeat exercises as many times as needed, replicating real-world scenarios. This affords a unique opportunity for students to refine their skills and gain mastery over complex engineering tasks.

**KEYWORD:** Digital Twins, Virtual Reality, Engineering Education, Cognitive Psychology, Immersive Learning, CDIO Standards: 6, 8.

## INTRODUCTION

In the era of Industry 4.0, Engineering Education faces the ongoing challenge of integrating emerging technological trends used in the industry into its curricula (Coşkun et al., 2019; Neaga, 2019). This challenge underlies the growing interest in Engineering Education Research (EER), which focuses on understanding how to effectively introduce digitalization concepts to future engineers. The question about digitalization not only involves learning about the transformation of the industry but also how to implement these digital tools in engineering practice (Evtushenko et al., 2023). In this evolving landscape, CDIO-based education and project-based learning have emerged as natural methodologies to achieve these goals, demonstrating a solid alignment with the anticipated challenges and technological trends in engineering (Goncharov et al., 2019; Säisä et al., 2017). However, the CDIO standards underwent significant adjustments in their 3.0 iteration to keep pace with the evolving industry demands. A notable change is the evolution of Standard 6, which previously focused solely on physical workplaces, to include digital workplaces (Malmqvist et al., 2019).

At the heart of these digitalized learning environments lie immersive technologies, which have become central in shaping the evolution of educational tools and systems across universities worldwide. For instance of this phenomenon, one can refer to recent works such as Sandyk et al. (2023) and Kontio et al. (2023). A notable example is the "JENII project" at the Arts et Metiers Institute of Technology, which aims to revolutionize engineering education by developing immersive and interactive digital twins. This project leverages active and immersive learning via simulations, enabling learners to acquire not only disciplinary knowledge but also personal and interpersonal skills and competencies in product, process, system, and service building within a virtually replicated environment. This project illustrates the shift from physical engineering learning workplaces to immersive, technology-enabled environments ensuring realistic interactions that an engineering student would typically encounter in an industrial setting. Within the CDIO framework, these digital twins act as virtual analogues to the physical workplaces, as outlined in Standard 6, and are designed for continuous optimization to enrich the learning experience.

In this paper, we delve into a brief yet comprehensive overview of cognitive psychology as it relates to the process of learning, examining how the integration of immersive technologies can further enhance the learning experience. Furthermore, we provide insights into the ongoing development of an immersive digital twin designed for an industrial forge, offering a practical demonstration of how these technologies can be implemented in a specific context. Finally, we explore the myriad educational applications of these immersive tools, detailing how they can be seamlessly integrated into the curriculum to facilitate effective learning. Additionally, we discuss potential innovative features and enhancements that hold the promise of revolutionizing the educational landscape even further, ensuring that students are equipped with the skills and knowledge they need to thrive in our rapidly evolving technological world.

A remarkable attribute of the digital twins is their potential to catalyze active learning, a fundamental component of CDIO (Standard 8). They provide students comprehensive access to realistic exercises applicable in the classroom and independent study contexts. These exercises are meticulously designed to simulate actions that students would undertake on actual machines, fostering a hands-on learning environment. The unique capability of these digital twins to facilitate repeated practice of these exercises mirrors real-world scenarios, offering students unparalleled opportunities to refine their skills and master complex engineering tasks.

In the following sections of this article, we outline the benefits and limits of immersive and interactive digital twins, as well as their implications for individual study and their potential in terms of additional pedagogical features. To illustrate each of these points, we will provide examples based on an existing digital twin that we are developing, simulating an industrial forge (see Figure 1).



Figure 1. Screenshot of the Industrial Forge Digital Twin

## **PEDAGOGICAL, ORGANIZATIONAL & MATERIAL BENEFITS**

Since some studies show positive effects of Virtual Reality (VR) on learning and others show negative or neutral effects, it is necessary to understand what differentiates them in order to identify the situations in which this type of medium is relevant. Immersive technologies appear to have potential whenever training requires users to feel a sense of social presence, i.e. the feeling of “being there” with a “real” person (Oh, Bailenson and Welch, 2018). This feeling is supported by stereoscopic 3D, immersion and consistent representation of the people we are with. In this case, individuals' emotional responses are analog to those measured in real-life situations. VR also has the capacity to generate a feeling of physical presence. A visually realistic environment is an effective way to provide a believable virtual experience. This means that VR can also familiarize the learners to a specific working place.

Through headset and gamepad position tracking, and through other parts of the body when adequate devices are used, VR is a medium that can lead users to adopt postures that are more or less equivalent to those they would adopt when carrying out a similar activity in a real situation. It is therefore particularly suitable for learning technical gestures or procedures. Immersive technologies can therefore be a way to make some learning more attractive. Finally, many studies show that course sequences based on immersive technologies often improve course attractiveness and learner satisfaction. For example, a VR anatomy course by Stepan et al. (2017) does not make any difference to the traditional course regarding anatomy knowledge, but it is considered more engaging, enjoyable, useful and motivating for students.

In some cases, making courses attractive is important for trainer satisfaction, students engagement and institutional image.

VR is often used to learn safety behaviors. Obviously, carrying out this learning with a digital simulator rather than in a real situation allows learners to test several configurations in a trial-and-error approach and to go as far as the accident without taking any risks for themselves or for the machines. Some educational scenarios can be developed specifically in this way, although it is not imaginable in a real situation. VR makes it possible to experience the accident more realistically than a non-immersive device (Fleury et al., 2023).

Investing in technological platforms at industrial scale for educational institutes can quickly turn out to be very expensive. One solution to reduce these costs is pooling between several campuses or educational institutes, or even with research laboratories. But other problems with student travel or management of shared resource planning may arise. Having a VR replication allows to have a lower-cost installation, accessible at any time and remotely. Even if digital technology cannot replace the physical environment in the concrete manufacturing of mechanical parts, preliminary tests to experiment some configurations in order to validate feasibility are also a source of budgetary savings. In forging, for example, when it comes to comparing and understanding the rheological behavior of different materials, it is possible to consider real shaping on a common material, like steel, whereas the same experiment for a more expensive material, like copper, could be carried out in the digital twin.

VR makes it easier to access certain work situations for people with disabilities. Even if, in certain cases, real workstations are not able to be adapted for security reasons, understanding an operational workstation allows them to better understand upstream work in a design department or in a process department, for example. Therefore, digital twins open new perspectives for these people who could not have been able to access these jobs before.

VR attracts the curiosity of younger populations, particularly through video games. In this context, immersing young learners in a virtual educational environment representing an industrial work situation could generate the same enthusiasm. These realistic situations will also make it possible to demystify bias about certain professions, and perhaps give rise to desires or vocations to continue graduate studies on specific training courses. For example, in the case of forging, the demonstrations given to undergraduate students showed that a blacksmith does not only work hot metal manually in free forging, but that industrial processes, with automated machines, exists and that the shaping is more a matter of physical phenomena than of force and/or chance. The profession is then identified more as an engineer's job and less as a craftsman one. Then, students can modify their choice of orientation accordingly. Professional sectors promote the development of these new educational tools which can attract talent where recruitment becomes difficult due to an unjustified bad image.

## **LIMITATIONS OF IMMERSIVE DIGITAL TWINS**

Currently, virtual reality headsets, not being common tools for students like computers or smartphones, require users to familiarize themselves with immersive digital twins' interaction modalities (especially controllers and buttons). Depending on the application's ergonomics and the guidance provided by the instructor, this learning curve may adversely affect the user experience or divert attention from content and learning processes. This limitation is more pronounced for immersive and interactive tools because they are less familiar in this context.

Therefore, it is essential to implement a user-centered design approach for digital twins to optimize the usability of these devices as much as possible.

This lack of democratization is also evident at the level of educational institutions. Higher education establishments today have "computer rooms" equipped with computers, but not all of them are equipped with "virtual reality rooms." However, providing such equipment is necessary as not all students have access to it. Additionally, this type of equipment imposes significant space constraints, with manufacturers often recommending around 9 square meters for a user to move and perform movements without space-related difficulties. In these conditions, it is challenging to envision having spaces large enough to accommodate virtual reality headsets for as many students as typically found in a practical session group (often one dozen students). In practice, the most likely scenario involves compromises in terms of space and the quantity of available equipment. For this reason, having an alternative version of the digital twin accessible on a computer, can be operated with a keyboard and a mouse, offers more possibilities for teachers because it is easier to allocate one computer per student. However, if ideal hardware conditions are met (small groups with an adequate number of headsets and ample space), the pedagogical potential is significant. Collaborative immersive practical work with monitoring by the instructor on a computer or even guidance by the instructor in virtual reality, for example (see Figure 2), becomes possible.



Figure 2. Illustrations of possible classroom situations with an immersive digital twin and a group of student supervised by a teacher.



Finally, practical work in engineering schools is generally connected to other pedagogical sequences: a theoretical lecture beforehand and a data analysis and debriefing phase afterward. VR is not a suitable tool for theoretical lectures preceding practical work because these lectures require students to take notes. However, note-taking in VR is complicated. Similarly, data analysis is usually carried out either with dedicated software or with a generic spreadsheet, for which VR is not the suitable medium. Once again, VR allows for a richer experience with presence and 1:1 scale visualization, which is really appropriate for practical sequences with the digital twins. For the more theoretical sequences, the existence of an alternative version on a computer/screen is crucial to fully implement a pedagogical scenario.

## INDEPENDENT STUDY

The work carried out by students at home or in open campus workspaces (such as libraries or study rooms) for revision before exams is a significant factor in the success of their studies (Keith, Diamond-Hallam & Fine, 2004). This personal work may be based on teachers' requests for revision, exercises, or projects, for example. It also corresponds to students' "spontaneous" work, where in their learning process, they allocate time to review their courses to reinforce their learning and achieve good grades in exams.

This personal work, whether spontaneous or prescribed, usually takes the form of reviewing student notes or course handout, or engaging in exercises based on course notes. It is often impractical for learners to replicate practical work at home, such as conducting a lab experiment, as they lack the necessary equipment. For instance, redoing a forging experiment would require machinery that they do not possess, and this holds true for most practical exercises (in chemistry, electricity, etc.). Undertaking independent personal work on campus to redo practical exercises is generally also unfeasible. Students cannot freely access potentially fragile and/or hazardous equipment, such as forge machinery, without supervision.

With the help of an interactive digital twin of the forge, learners have the opportunity to redo practical exercises from home or on campus whenever they wish for revision. This tool goes beyond a simple video presentation of the content because students can actively replicate the actions, such as handling metal pieces, themselves (see Figure 3).



Figure 3. The learner manipulates a billet using a wrench

One challenge of students' personal work is to achieve a sufficient level of engagement to elicit these behaviors. Umaralieva (2021) actually advocates the use of multimedia documents to promote personal work. The positive effects of immersive technologies on the pleasurable and motivating nature of the activity also offer a potential that can be interesting for independent learning and revision. In cases where learners have the freedom to do exercises for practice or not to do so, having access to an attractive practice tool can make a difference to the amount of practice done.

## **ADDITIONAL PEDAGOGICAL FUNCTIONALITIES**

The immersive and interactive digital twins in the JENII project offer educational benefits through their facilitation of active and experiential learning (Standard 8) and by proposing a pedagogical approach that incorporates professional engineering issues (Standard 7) while aiding knowledge acquisition through specific features. The present section will explore a range of these potential features within this learning medium: attentional guiding, pedagogical agents, visualization of invisible phenomena and generative learning features.

**Attentional guidance** is a means of ensuring that learners select the right information at the right moment. Active learning is generally considered positive for students in terms of satisfaction and efficiency (standard 8). However, this active learning must be conducted under relevant conditions to enable the creation of a coherent mental model. In VR, the addition of spatialized annotations in the 3D scene is a way to facilitate the selection of information (Vogt, Albus & Seufert, 2021). Similarly, when learners need to perform a series of actions, it is possible to add exogenous guidance, such as highlighting an object to manipulate, for example.

**Pedagogical agents** (PAs) representing virtual entities with social skills are increasingly considered valuable in education (Dai et al., 2022). These PAs excel in delivering content that is not only relevant but also engaging in virtual learning environments, enhancing interaction with students. This approach is grounded in the social agency theory, suggesting that educators' social signals boost student engagement and foster a more profound desire to learn. Consequently, a PA effectively employing these social cues can significantly improve learning outcomes (Sinatra et al., 2021). Key attributes of effective PAs include utilizing a human-like voice instead of a synthetic one (Craig & Schroeder, 2017), exhibiting a range of facial expressions rather than maintaining a neutral expression (Bringula et al., 2018), employing specific gestures (Davis & Vincent, 2019) and presenting an appearance that aligns with the study topic (Schmidt et al., 2019). PAs serve not merely as instructional tools but as dynamic entities that fit into the complex social setting of integrated learning experiences. Their adeptness in both verbal and non-verbal communication facilitates the transmission of knowledge and situates this learning within a socially engaging context. Integrating Large Language Models (LLMs) such as GPT can significantly enrich interactions between students and PAs (Pataranutaporn et al., 2022). This enhancement facilitates knowledge sharing but also aids in developing interpersonal skills and familiarizing future engineers with sophisticated human-machine interfaces.



Figure 4. Virtual embodiment of the instructor

In the digital twin scenario of the forge, the PA is envisioned as an interactive virtual embodiment of the instructor, enabling real-time, dynamic interactions with learners in the virtual environment (Figure 4). Moreover, when powered by generative AI, the PA can be transformed into an ideal professional role model, offering students a multifaceted learning experience.

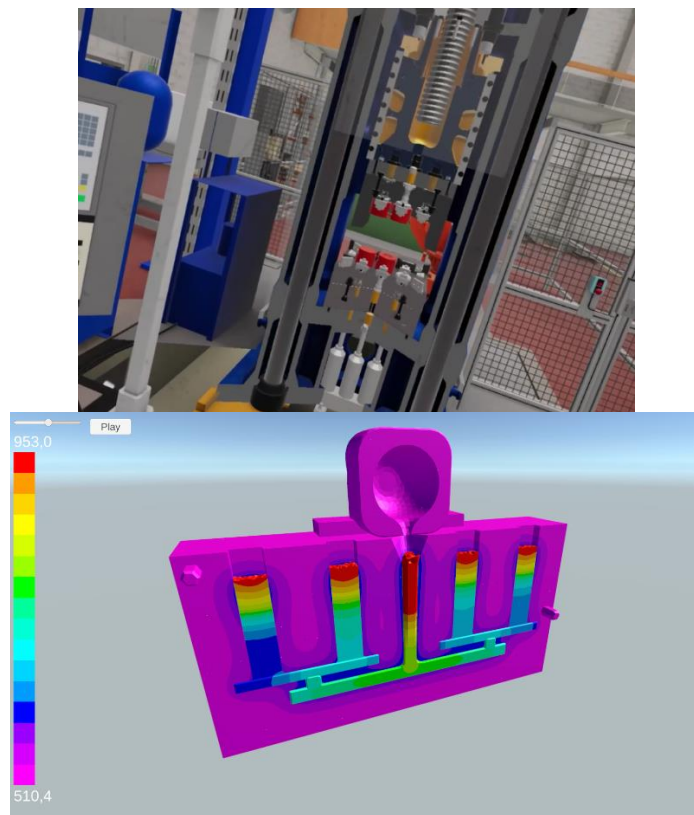


Figure 5. Cross-section of a screw press in operation (left) and visual representation of part cooling dynamics.

3D representations allow the **visualization of invisible phenomena in realistic context**: cross-sectional views of machines in operation or even representations of invisible physical phenomena (airflow, heat distribution, etc., see Figure 5). VR provides the additional advantage of allowing the visualization of phenomena from a first-person perspective and at a 1:1 scale, also paving the way for intuitive interaction with the data (Christmann et al., 2022).

Engaging in behaviorally active learning situations does not automatically ensure cognitive engagement for learners. One effective method to address this is the application of **generative learning strategies**, which facilitate the reorganization and assimilation of new knowledge (Fiorella & Mayer, 2016). Such strategies typically involve synthesizing knowledge through written summaries, a process that helps structure and solidify the learning. However, immersive virtual environments often do not support traditional notetaking, leading learners to remove their VR headsets for writing activities in the physical realm (Klingenberg et al., 2023; Parong & Mayer, 2018). This shift creates a disconnection between the practice environment and the space where the reflection occurs. To bridge this gap in our digital twins, we have developed a feature that enables learners to record their voice and interactions with the environment using their avatar's embodiment. This user-friendly feature includes interfaces for starting and stopping recordings (Figure 6). The generative nature of this activity presents two critical advantages over standard notetaking. First, it stimulates two learning modalities to build a robust mental representation: verbalization through self-explanation and physical enactment. Second, the activity occurs within the learning environment, integrating the knowledge in a realistic setting.



Figure 6. User interfaces included in VR app for recording and visualization functionalities

To maximize the pedagogical benefits of this feature, the recordings are stored and available for review. The reviewing function allows students who engage with this functionality during practical exercises to access their recordings later on alternate devices, such as VR systems or PC. For example, students can record their techniques and thoughts while shaping a metal piece in the virtual forge. Later, they can review these recordings to analyze their methods and decision-making process, deepening their understanding of forging and identifying improvement areas. This reflective practice, firmly rooted in the immersive environment, enriches practical skills and cognitive learning.

## DISCUSSION

We have observed that Digital Twins have a number of advantages and limitations. Additionally, we have discussed additional potentialities that could be realized with some technical developments. However, as highlighted by Mayer, Makransky, and Parong (2023), it is crucial to adopt a cautious and rational approach, grounded in evidence, when selecting effective digital tools.

VR proves to be a suitable medium for experiential learning as it allows for immersive scenarios. For this reason, educational applications often involve step-by-step guidance, where users simply follow instructions to perform various actions. Nevertheless, learning by doing does not guarantee comprehension in every situations. We could refer to this phenomenon as the "GPS Effect": when you navigate a route guided by GPS, the journey is easy to execute, but it is not memorized by the driver. Conversely, learning the route on a map

before the journey is more challenging but facilitates memorization. We believe this "GPS Effect" may occur in virtual reality learning, and step-by-step guidance might not be an optimal solution. Ongoing experiments in our research will help formalize this issue and propose alternatives.

Virtual agents represent another potential lever for enhancing learning. Our ongoing work will examine the impacts of the high interactivity made possible by generative AI on both learner satisfaction and learning performance.

Lastly, generative learning is identified as highly effective. Fiorella and Mayer (2016) have categorized possible generative learning activities. Since VR is impractical for note-taking, we have conceived a technical device that could, hypothetically, combine the advantages of multiple generative learning tasks. This system, recording immersive visual and auditory capsules, is currently under experimentation and will be the subject of a publication.

These ongoing studies, among others, will provide evidence regarding specific features that can enhance the pedagogical value of immersive digital twins for learning. Through rigorously evaluated optimizations, these types of tools can potentially become valuable alternatives in educational settings.

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# IMPLEMENTING AI ETHICS EDUCATION: ENGINEERING COMPETENCIES FOR SUSTAINABLE SOCIETAL IMPACT

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## ABSTRACT

The societal impact of engineering practices demands a profound sense of responsibility among engineers to tackle global challenges, yet necessary skills related to ethics, sustainability, and teamwork remain generally weak among engineering professionals. An interdisciplinary course can act as a springboard for integrating transferable skills and knowledge recommended by CDIO into engineering education. A master's seminar at RWTH Aachen University is training engineering students on ethics, responsibility, and sustainability in the context of Artificial Intelligence (AI), topics which are requisite for engineers to understand societal needs and their active role in society. Through active and integrated learning, this course provides students with a holistic view of technology embedded within the diverse societal contexts. While evaluating students' anonymized reflection papers using Qualitative Content Analysis (QCA), we found that many students appreciated the unique seminar structure, and the seminar topics. We speculate that interest in the course and creative freedom, among other factors, may have fostered deeper engagement and plans for lifelong learning. Many students considered this course an "eye opener" since it introduces them to interdisciplinary and holistic thinking. This paper presents the course structure, methodology, and findings from a QCA of students' reflections to approach the following research question: *What competencies from CDIO Syllabus 3.0 can be acquired in an interdisciplinary course for engineers such as this seminar on AI ethics, and how?* We also discuss planned improvements based on student feedback, which adds to the discourse on how to best implement an interdisciplinary course that accomplishes several CDIO Syllabus objectives and Standards.

## KEYWORDS

AI, Ethics, Engineering, Sustainability, Competencies, Standards: 1, 2, 6, 7, 8, 11, 12, Optional Standard 1

## INTRODUCTION

Industry 4.0, accelerated by and largely composed of AI, demands a shift in engineering education (Bühler et al., 2022), as does Industry 5.0's focus on a human-centered approach including socially sustainable technology (Renda et al., 2021). However, competencies related to ethics, sustainability, responsibility, and teamwork remain generally weak among



engineering professionals (Kovacs et al., 2023), even though they are requisite for engineers to understand societal needs (Kenyon, 2023) and their active role in society (Kjelsberg & Kahrs, 2023).

A master's seminar at RWTH Aachen University called *Innovation & Diversity* (I&D) is now training engineering students on ethics, responsibility, and sustainability in the context of AI (see also Decker et al., forthcoming). In self-organized groups, students complete a project-based portfolio examination, which has been recommended for integrating ethical themes (Angelva et al., 2023), professional and sustainability competencies, and being highly motivating for students (Hansen & Sindre, 2023; Pettersen & Lundqvist, 2023). Through active and integrated learning, this course provides students with a holistic view of technology embedded within the diverse societal contexts which are often largely overlooked in engineering education (Cañavate et al., 2015). This interdisciplinary course on AI ethics shall therefore serve as a springboard for integrating these and numerous other transferable skills and knowledge recommended by CDIO (Crawley, et al., 2011; Malmqvist et al., 2022), such as reasoning, problem solving, holistic thinking, communication, digital literacy, balancing competing objectives, and the impact of engineering on society.

Thus, this paper presents the course structure, methodology, and findings from a Qualitative Content Analysis (QCA) of students' reflections to approach the following research question (RQ): *What competencies from CDIO Syllabus 3.0 can be acquired in an interdisciplinary course for engineers such as this seminar on AI ethics, and how?*

### **Related Work**

Engineers have long been recognized as shapers of societal progress, designing the world we inhabit (Winner, 1980) and tackling global challenges (Yortsos, 2021). However, this influence brings with it a profound responsibility to instill the right values, necessitating a focus on ethical considerations (Sunderland, 2019; de Vries, 2022). The growing awareness of the societal impact of engineering practices has led to the widespread acknowledgment of the need for engineering ethics to serve as a compass for engineers, guiding them towards decisions that consider the broader implications of their work on individuals and communities (Bosen et al., 2023; Decker et al., 2021; Decker et al., 2022).

In recent years, artificial intelligence (AI) has become an integral part of our daily lives, exerting a substantial influence, both visible and invisible, on thousands of people. The use of AI technologies, however, has raised ethical concerns, with instances of problematic consequences (Barocas et al., 2022; Barocas & Selbst, 2016). This underscores the critical need for ethical considerations during the development and deployment of AI technologies in all stages of development and deployment. This influence extends to the engineering profession, where AI is increasingly employed to enhance efficiency and capabilities. As AI becomes intertwined with engineering practices, the intersection of AI, ethics, and engineering emerges as a critical focal point (Decker et al., forthcoming).

Higher education institutions play a crucial role in shaping the ethical foundations of future professionals, and this is particularly relevant in engineering education (Mitchell, 2023). Criticism has been directed towards the predominantly technical focus of engineering study programs, suggesting that students may lack the necessary skills to navigate morally opaque situations (Devon, 1999; Pierrakos et al., 2019). However, many engineering education accreditation criteria remain vague about how to implement ethical engineering courses (Saltz et al., 2019). While engineering ethics often focuses on codes of conduct and practical case

studies, a deficiency exists in incorporating ethical theories into the curriculum (Bouville, 2008). Pierrakos et al. (2019) propose a broad perspective, stating that ethics should inform not only rare, extreme decisions but also guide engineers in their daily problem-solving, interactions with colleagues and clients, and relationships with various stakeholders in the community. Studies have consistently demonstrated the positive impact of introducing ethics early in the education of engineering students. The earlier students engage with ethical considerations, the better equipped they are to incorporate ethical considerations into their professional practice. Moreover, research suggests that ethics is most effectively taught when considerations are interwoven into every course throughout the curriculum, fostering a holistic approach to ethical decision-making (Mitchell et al., 2021; Pierrakos et al., 2019).

### ***The Innovation & Diversity Seminar***

As part of the research group Gender and Diversity in Engineering (GDI) at RWTH Aachen University, we developed an elective master's seminar called *Innovation & Diversity* (I&D) with a focus on ethical AI in (civil and environmental) engineering (see also Decker et al., forthcoming). The GDI is led by a bridging professorship between the humanities and engineering and, thus, anchored at two different faculties. This focus on interdisciplinarity brings together students from different disciplines. Therefore, the seminar is attended by students from civil engineering, environmental engineering, business administration and engineering, sustainable management of water and energy, construction and robotics, sociology, communication studies, and the bachelor program for linguistics and communication studies. The interdisciplinarity of the I&D seminar is offered by this mix of students from different disciplines as well as the interdisciplinary nature of the topic of AI ethics in engineering; it necessarily involves topics from sociology, ethics, data science, and engineering, bringing with it novel educational experiences. In the inaugural semester in Winter 2022-2023, 20 students attended the seminar.

The course introduces students to basic technical aspects of AI as well as societal impacts in the context of AI as an innovative technology. The seminar does not instruct students on developing the algorithms themselves but should allow them to understand how they operate, be able to work with them, and critically reflect on them in the future. The seminar begins with a brief introduction on the basics of AI so that students have a high-level understanding of the design, development, and implementation of AI. Societal impacts of AI are then introduced, comprising discussions on justice, responsibility, diversity, and sustainability. Ethical guidelines for AI were compiled and adapted into a checklist meant as a starting point to aid students in their ethical evaluations of real-world AI applications. Ethical checklists are likely popular in policy and industry due to the ease of legal compliance that they enable. Although checklists may also overgeneralize ethical applications and may lead to complacency, we nevertheless chose to work with a checklist, as many others do, since they provide an easy way to remember broad principles and make ethics more approachable, while still encouraging creative thinking. Our list consists of the FAST (Fairness, Accountability, Sustainability, Transparency; Leslie, 2019) and FACT (Fairness, Accuracy, Confidentiality, Transparency) ethical principles for AI. Additional guided reading tasks extend students' knowledge and delve deeper into technical and ethical aspects of AI and real applications of AI in engineering. As per students' request, we also offer a supplementary session on scientific writing and citation.

Finally, a portfolio examination mainly composed of groupwork tasks put the students in charge of the direction of their learning as they critically reflect on the use of AI in engineering using the examples that they discover in their own independent literature research. The portfolio examination consists of four different examination tasks (ETs). Groups of 4-5 students work

together on the first three tasks, each task building upon the previous one. The first task (ET1) has groups select an example of AI in engineering in which the AI has degenerative effects on human lives and answer a set of questions about this example. The second task (ET2) instructs each group to jointly write a 10-15-page paper introducing and evaluating their chosen example. One week before the submission deadline of ET2, a mediated, online peer feedback session allows students to meet with representatives from other groups to discuss their work so far and exchange feedback. For the third task (ET3) groups design scientific posters that present the findings from their paper and 90-second videos that present possible solutions or recommendations for action in response to the ethical risks or issues discovered. On the penultimate session of the seminar, groups take turns presenting their work in a mock conference. Finally, after the presentations of ET3, the last task (ET4) asks students to individually write reflection papers of 1-2 pages answering the following three open-ended questions: What was most interesting in the course? What was most surprising? What are your takeaways?

## METHODS

Due to the open-ended nature of ET4, students provided insights that went beyond the three questions that were presented to them when prompted to complete the ET. Furthermore, students self-reported their acquired competencies, among other things, which inspired new and more precise themes to be analyzed. We thus realized the wealth of valuable information that the reflections provided and became interested in further exploring students' self-reported positions on the topics of the course and on the course itself (see also Decker et al., forthcoming) as well as the competencies successfully acquired during the seminar. Hence, this paper conducts an exploratory thematic analysis of students' ET4 reflection papers with respect to the RQ.

All twenty ungraded reflection papers of ET4 form the basis of our post-hoc qualitative data analysis, although it should be noted that one reflection paper was of low-quality as it was very short, superficial, and did not provide much valuable insight. Since students were allowed to answer in an unstructured format, we found a complex overlapping of categories, which lends itself to Kuckartz's QCA (2019) to discover and compare these themes while supporting an exploratory style of analysis. Before beginning our analysis, we cyclically defined categories for and coded our students' anonymized reflection papers in accordance with Kuckartz's (2014, 2019; Kuckartz & Rädiker, 2019) methodology and using MAXQDA qualitative data analysis software. This was done in three cycles: (1) a concept-driven (deductive) cycle to develop a first draft of our main categories, (2) a second data-driven (inductive) cycle to refine our list of main categories via open-coding and finish coding all segments for main categories, and (3) a final inductive cycle to derive and code for subcategories.

Based on our research questions and the ET4 writing prompt, the first cycle consisted of deductively compiling an initial list of 13 main categories while individually coding 5 of the 20 papers. The segment length was not limited; we agreed that a coded segment should include what was necessary to view it out of context and still understand the student's argument as well as why it fit in the assigned category. During this first cycle, we also inductively discovered other categories, merged, and renamed categories with significant overlap. We reviewed and edited the coding of the initial 5 papers before continuing with the next 5 papers. Subsequently, we compared our coded segments for all main categories to finalize our coding rules before coding the rest of the 20 papers and resolving any coding disagreements, thus concluding the second cycle. This "consensual coding" strategy (Kuckartz, 2014, p. 46) was preferred over

intercoder reliability coefficients for its simplicity in qualitative text analysis and full agreement at the end of coding. The final eleven main categories were thus identified: *Course Structure and Methods*, *Expectations Before the Seminar*, *Interest in the Seminar Topics*, *Value-Neutrality of Technology*, *Relevance of AI Ethics (to a Future Engineer)*, *Applications of AI in Engineering*, *Previous Experience with AI*, *Previous Experience with Ethics*, *Surprising*, *Misunderstandings*, and *Challenges*. In the third cycle, we inductively derived possible subcategories for each main category by reviewing all the coded segments of a single main category and combined subcategories where possible before assigning each main category segment to one or more of its subcategories. Four of the final eleven main categories are relevant to this paper and are listed in Table 1 along with the relevant subcategories. Categories remained non-exclusive in the sense that some excerpts may belong to multiple overlapping categories. This non-exclusive categorization allowed us to analyze segments from various angles.

Table 1. Relevant Categories and Subcategories for Thematic Analysis in This Paper (\* indicates subcategories used in the QCA that do not have their own dedicated sections.)

| Main Categories<br>(# Coded Segments,<br># Students Out Of 20) | Subcategories<br>(# Coded Segments, # Students Out Of 20)              |
|----------------------------------------------------------------|------------------------------------------------------------------------|
| <b>Surprising (37, 19)</b>                                     | Need for Interdisciplinarity in Technical Fields (8, 7)                |
| <b>Course Structure and Methods (109, 19)</b>                  | Course Organization and Examination Structure (28, 11) *               |
|                                                                | Topics and Tools (31, 14)                                              |
|                                                                | Class Activities and Examples (6, 4) *                                 |
|                                                                | Assignments (22, 12)                                                   |
|                                                                | Groupwork (21, 12)                                                     |
|                                                                | Improved Skills (10, 6)                                                |
|                                                                | Creative Freedom (4, 3)                                                |
|                                                                | Overall Evaluation / Compliments (21, 9) *                             |
|                                                                | Constructive Criticism / Suggestions (14, 5) *                         |
| <b>Challenges (22, 13)</b>                                     | Applying Ethical Principles (5, 5)                                     |
|                                                                | Finding Relevant Literature and Choosing an Appropriate Topic (9, 9) * |
|                                                                | Challenging Groupwork (8, 6) *                                         |
| <b>Misunderstandings (13, 10)</b>                              | N/A                                                                    |

Keywords and phrases for the *Surprising* category included “surprising,” “could not believe,” or “did not expect.” Statements in this category refer to unexpected discoveries. From the “surprising” main category, we derived six subcategories. Segments in the subcategory, *Need for Interdisciplinarity in Technical Fields*, discuss the desire or need for combining technical fields with non-technical fields such as ethics, sociology, and human–technology interaction in education and in the workforce. This could be described, for example, as a need for engineers to understand diversity or how AI affects humans.

The *Course Structure and Methods* category includes comments regarding course assignments, the portfolio examination style, group work, in-class tasks or interactions, and a partial evaluation of any of these elements or overall evaluation of the seminar. This large main category was subdivided into nine non-exclusive subcategories. *Course Organization and Examination Structure* includes but is not limited to mentions of peer feedback sessions, other structured opportunities to provide feedback, lecturer content delivery, group formation, the supplemental lecture on citations and writing, sharing group presentations on the last day, and the portfolio examination structure. In this case, discussion of the portfolio examination should

be specifically related to the division of the examination into several ETs, not related to the task contents, timing, or workload (which will be captured in other subcategories). The *Topics and Tools* excerpts discuss seminar topics covered—especially the relevance or importance of topics to AI, engineering, or students—and tools we provided to students such as the FAST (Fairness, Accountability, Sustainability, Transparency; Leslie, 2019) and FACT (Fairness, Accuracy, Confidentiality, Transparency) ethical principles and checklist. *Class Activities and Examples* refer to any specific examples or interactive activities that were presented during the seminar. Of particular interest are examples and class activities that made an impression on a student and helped them understand key seminar concepts. The *Assignments* subcategory covers optional reading task and compulsory ET content, including independent research, reading and writing academic papers, creating a scientific poster, and students' own presentations. When students discuss working in a group, such as the group dynamics, challenges, and successes, this belongs in the *Groupwork* subcategory. Again, ET content and portfolio examination structure belong to other subcategories. Mentions of both ET content or structure and groupwork in the same segment would result in non-exclusive assignment to both subcategories (“assignments” and “groupwork”). Many students reflected on their *Improved Skills*, such as critical thinking, analytical and interpersonal skills, digital tool literacy, and academic literature research skills. Moreover, some of the interpersonal and professional skills include compromise, communication, groupwork, and time management. The keywords for the subcategory *Creative Freedom* are “creative,” “creativity,” and “freedom.” Although not originally defined, these keywords referring to the creative freedom allowed by the ETs reoccurred in several students' reflection papers such that we decided it was important enough to have its own sub-category. It seemed a significant and unique experience for many students. Broader excerpts related to *Overall Evaluation / Compliments* have a positive or neutral evaluative valence. Optional keywords include “overall,” “liked,” “special.” More importantly, the text must refer to a positive or neutral evaluation of the seminar overall or a positive evaluation (compliment) of a specific aspect of the seminar. Lastly, *Constructive Criticism / Suggestions* refer to aspects of the seminar that some students did not like and/or suggestions they had for improvement of the seminar in future semesters. This is an exciting sub-category that will help us make the appropriate adjustments before the next semester.

The *Challenges* category comprises of any difficulties students had during the course, including but not limited to challenges regarding group work, researching AI applications in engineering, and applying ethical principles. Keywords for this category were, for example, “challenging” or “difficult.” This main category was further subdivided into four subcategories with only one instance of overlapping assignment; they are otherwise mutually exclusive. The subcategory, *Applying Ethical Principles*, includes segments discussing the difficulty students encountered while attempting to evaluate real applications of AI in engineering for the ethical principles learned in class. *Finding Relevant Literature and Choosing an Appropriate Topic* covers statements describing the difficulty in attempting academic literature research for the first time, finding academic literature relevant to the seminar in that it sufficiently describes an application of AI in engineering, and selecting an appropriate application area or example to work through in group assignments for the rest of the seminar. Segments that belong to the *Challenging Groupwork* subcategory always also belong to the “groupwork” subcategory of “course methods and structures,” but not necessarily the other way around. These segments refer to challenges encountered during groupwork, such as challenges regarding selecting group members, scheduling meetings that all group members can attend, equally dividing groupwork, communicating with group members, making compromises in groupwork, and understanding the requirements of group assignments when group members had different interpretations of the instructions.

*Misunderstandings* became a category when we encountered instances of students making claims that were incorrect or showed a fundamental misunderstanding of the seminar content. These are highlighted as a main category to investigate any common misunderstandings among students so that these can be more carefully explained in future semesters.

In this paper, we mainly analyse the main categories Course Structure and Methods, Challenges, and Misunderstandings as we are interested in *how* a course such as I&D can teach sustainability and other competencies from the CDIO Syllabus. We refer to future work (Decker et al., forthcoming) for analysis of the other categories.

## **RESULTS AND DISCUSSION**

In this section we present the results of our analysis of students' anonymized reflection papers with respect to the competencies that can be learned from a course such as the seminar presented in this paper, as well as how they can be achieved. We are particularly interested in the competencies that can transfer from this interdisciplinary course to other courses or professional activities with a focus on different topics. We first discuss how several competencies from the (proposed) CDIO Syllabus 3.0 (Malmqvist et al., 2022) can be achieved. Then, we combine our findings from the Challenges and Misunderstandings main categories to discuss some difficulties in realizing the intended competencies. Finally, compliance with CDIO Standards 3.0 (Malmqvist et al., 2020a, 2020b) is examined.

To differentiate between students' reflections regardless of anonymization, we will refer to individual papers by a number randomly assigned between 1 and 20 for the 20 papers received. Thus, every quote will be followed by a number between 1 and 20 and a page number indicating on which page of the reflection paper the segment was found. This permits the assignment of different segments to the same student's opinion.

***RQ: What competencies from CDIO Syllabus 3.0 can be acquired in an interdisciplinary course for engineers such as this seminar on AI ethics, and how?***

Our research question specifically focuses on the competencies that can be learned from a course such as the I&D seminar. Hence, we present the prescriptions of the (proposed) CDIO Syllabus 3.0 (Table 2; Malmqvist et al., 2022) below. This framework forms a basis of our understanding of valuable competencies for engineering students as we perform our analysis with respect to it. We mainly discuss the RQ with respect to the competencies (up to the second level of detail: X.X) prescribed in sections 2 and 3 of the proposed CDIO Syllabus 3.0, but we also examine 1.4, 4.1, 5.1, and 5.3. For brevity in the analysis below, we will refer to competency sections from the proposed CDIO Syllabus 3.0 as SX.X (e.g., S1.4). See Table 2 for a concise overview of I&D's compliance with the entire proposed CDIO Syllabus 3.0.

### ***Surprising: Need for Interdisciplinarity in Technical Fields***

Often times students are only aware of "ethics playing an important part of machines and AI in [movies] and TV shows with extreme cases, for example, 'I, Robot' and 'Black Mirror' but it never occurred to [one student] that Ethics could be applied to other sectors, least of all to construction [in civil engineering]," (2, p. 1; S2.3, S2.5, S4.1). While attending the course, students realized that "discrimination in AI is more common than previously thought and its connection to diversity is equally surprising," (4, p. 1). One student reflected after the course, "Initially, I had a narrow understanding of ethics and mostly thought of data privacy and safety

when thinking about ethics. However, throughout the course and through group discussions, I learned that there are many more aspects to consider, such as accountability, transparency, and social impact,” (S1.4, S2.1, S2.3) and was also “surprised by the relevance of the ethics for the innovation process,” (5, p. 1-2). Another student reflected, “As an engineer, I was always considering the technical aspect of it. Nevertheless, I got to know that the social aspect is significantly important, and it could be a key element in deciding whether AI should be implemented or not,” (6, p. 1; S2.4, S2.5, S4.1). Without interdisciplinary content covering knowledge from social sciences and humanities (S1.4), students in technical fields would be unlikely to understand the connection between social and technical aspects. In fact, as our students have explained, they would be unlikely to have ever been exposed to ideas such as societal impact and accountability in their purely technical courses. These quotations show that during this interdisciplinary seminar, our students were able to grasp the importance and interconnectedness of ethics, societal impact, and (engineering) technology, enabling sustainable development within societal and environmental contexts.

Table 2. (Proposed) CDIO Syllabus 3.0 At the Second Level of Detail (Malmqvist et al., 2022). (+ = largely covered; ~ = partially covered; – = out of scope)

| (Proposed) CDIO Syllabus 3.0                                                                                                                         | Fulfilled by I&D |
|------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| <b>1. Fundamental Knowledge and Reasoning</b>                                                                                                        |                  |
| 1.1 Knowledge of Underlying Mathematics and Science                                                                                                  | –                |
| 1.2 Core Engineering Fundamental Knowledge                                                                                                           | ~                |
| 1.3 Advanced Engineering Fundamental Knowledge, Methods, and Tools                                                                                   | ~                |
| 1.4 Knowledge of Social Sciences and Humanities                                                                                                      | +                |
| <b>2. Personal and Professional Skills and Attributes</b>                                                                                            |                  |
| 2.1 Analytic Reasoning and Problem Solving                                                                                                           | +                |
| 2.2 Experimentation, Investigation, and Knowledge Discovery                                                                                          | ~                |
| 2.3 System Thinking                                                                                                                                  | +                |
| 2.4 Attitudes, Thought, and Learning                                                                                                                 | +                |
| 2.5 Ethics, Equity, and Other Responsibilities                                                                                                       | +                |
| <b>3. Interpersonal Skills: Collaboration, Teamwork, and Communication</b>                                                                           |                  |
| 3.1 Teamwork and Collaboration                                                                                                                       | +                |
| 3.2 Communications                                                                                                                                   | +                |
| 3.3 Communications in Foreign Languages                                                                                                              | +                |
| <b>4. Conceiving, Designing, Implementing, and Operating Systems in the Enterprise, Societal, and Environmental Context – The Innovation Process</b> |                  |
| 4.1 Societal and Environmental Context                                                                                                               | +                |
| 4.2 Enterprise and Business Context                                                                                                                  | –                |
| 4.3 Conceiving, System Engineering, and Management                                                                                                   | ~                |
| 4.4 Designing                                                                                                                                        | ~                |
| 4.5 Implementing                                                                                                                                     | ~                |
| 4.6 Operating                                                                                                                                        | ~                |
| <b>5. The Expanded CDIO Syllabus: Leadership, Entrepreneurship, and Research</b>                                                                     |                  |
| 5.1 Leading Engineering Endeavors                                                                                                                    | ~                |
| 5.2 Engineering Entrepreneurship                                                                                                                     | –                |
| 5.3 Research                                                                                                                                         | +                |

### **Course Structure and Methods: Topics and Tools**

Most students appreciated the introductory lectures. Students learned that “diversity is not a simple word, it is indeed complex and it has different concepts,” (6, p. 1). As another student articulated, “topics discussed in the lecture broadened my horizon and understanding on fairness, discrimination, and diversity... Understanding and especially defining diversity is an important foundation in order to actually consider and respect the diversity of societies while making use of AI,” (10, p. 1) or other engineering innovations (S1.4, S2.3, S2.5, S4.1). During one class, students were asked to fill out a paper asking them to which diversity dimensions they felt that they belong. One student stated that “the dimension paper that [they] filled out... showed new facets to the topic of diversity [that they] previously didn’t pay attention to and helped understanding the term diversity and its importance in the context of AI-models... while showing simultaneously the challenges that arise when trying to measure diversity objectively,” (4, p. 1; S1.4, 2.4, 2.5, 4.1). Another explained that the course “[emphasized] the importance of staying updated and informed about the advancements in [engineering innovations such as] AI technology, as well as being aware of the ethical and social implications of its use,” (18, p. 1). This shows that at least some students learned the value of keeping oneself up to date with ethical discourse and engineering advancements (S2.4, S2.5, S4.1). Overall, students lauded the introductory lectures, which provided necessary background knowledge on AI as well as relevant sociological and ethical topics, enabling a holistic understanding of engineering systems embedded within societal and environmental contexts.

### **Course Structure and Methods: Assignments**

The assignments given in the various ETs provided students with opportunities to complete new types of tasks, such as writing an academic paper for the first time and “helped the students develop knowledge about different ways of presenting results,” (10, p.1; S3.2). One student commented, “it was interesting to choose an example [use case] by ourselves,” (14, p. 2) while another elaborated, “I liked that we had a concrete practical example, in which we had to consider the possible negative ethical aspects of AI devices, but also possible solutions on how to ensure that AI systems are implemented in a way that maximizes the benefits for the society, while minimizing their negative impacts,” (19, p. 2; S2.1, S2.3, S2.4, S5.1). It seems that it is unusual for students to be offered a chance to select the subject of their studies within the context of a course. Through the ETs, students also gained awareness about current AI applications, the complexity of ethically evaluating AI, and the possible negative effects of using AI (S2.5). Especially during ET3 presentations, students gained “an insight into relevant fields where the application of AI is becoming an integral part of it,” (7, p. 2). By being present for other groups’ presentations, students were able to learn about other AI applications in engineering they had not researched as well as observe different styles of presentation. Many students commented that they particularly appreciated seeing other groups’ presentations near the end of the course. Thus, students gained exposure to different AI applications in engineering, awareness of AI’s complex and at times negative effects (S2.5), researched a practical use case (S2.2, S5.3), and practiced presenting their results or reflections in various ways: via academic paper, scientific poster, video crafted using digital tools, oral presentation, and reflection paper (S3.2).

### **Course Structure and Methods: Groupwork**

Many found groupwork to be challenging, but as will be discussed, it was worthwhile for the relevant professional and future skills learned that will be directly applicable to future teamwork. Several students expressed that it was their first time engaging in groupwork in university and



that they felt inexperienced when it came to working as a team though having a course with groupwork was “refreshing,” (11, p.1). Many also enjoyed that they were able to organize themselves into diverse groups of students from different social backgrounds since this led to more diverse ideas and discussions (S3.1). One student explained, “the diversity of our team allowed for a wide range of ideas and perspectives to be considered, which ultimately led to a final product that we all were happy with. Despite some disagreements, we were able to work with each other. This most likely also helped us prepare for the workplace, where things won't always go as planned,” (14, p. 3). Although some found groupwork to be challenging due to difficulties coordinating meeting times and dividing tasks (S2.4, S3.2), some likewise explicitly stated that they thought that the groupwork required in this seminar might help them in the future. For example, one student wrote, “I also appreciated the opportunity to work in such a diverse group during the course. Our group consisted of people with different backgrounds and perspectives, which led to stimulating discussions and a more comprehensive understanding of the material [S3.1] ... As a contrast from the other courses when I had to write exams or other essays on my own, I found the group work to be quite helpful. I was able to pick up soft skills that will benefit me in both my future academic and professional activities,” (8, pp. 2-3). Another student further reflected that “the group work was as challenging as it was enriching,” (10, p.1). Incorporating groupwork into the ETs therefore enabled students to develop their interpersonal collaboration skills (S3) as well as personal skills such as time management, organization, and task prioritization (S2.4). This will undoubtedly be helpful in future work.

### **Course Structure and Methods: Improved Skills**

Five students specifically referenced groupwork as the source of their improved personal and interpersonal skills including communication, presentation, conflict resolution, time and task management, as well as digital literacy (S3.2). Other than the skills improved during groupwork, one student explicitly stated, “the course helped me develop my critical thinking skills,” (8, p. 2) necessary for ethical evaluation and subsequent solution generation in ET2 and ET3 (S2.3, S2.4, S5.1). Additionally, since the seminar was conducted in a university in Germany, English was a foreign language for most students, and this course allowed them to practice speaking, reading, and presenting in an academically appropriate level of English. Even communication within some groups was conducted in English due to diverse backgrounds (S3.3). At least two students clearly expressed that they saw a great improvement in their ability to research, read, and comprehend scientific literature (S2.2, S5.3). One student commented, “from the perspective of analysing skills, like reading scientific papers and writing an essay, I would say that this course has helped me a lot to improve for the future. It displayed my weakness regarding reading scientific papers (this was really exhausting) and lacking ability to find appropriate wording in the essay,” (11, p. 1) while another shared, “the individual research for appropriate articles was one of the most interesting but also most challenging aspects of the course [S2.2, S5.3]. I could develop my research abilities here. I gained knowledge on how to read articles more quickly and effortlessly, as well as how to find relevant papers. Along with finding relevant papers, I learned how to work with scientific literature. By the end, I was able to comprehend texts that were difficult to understand,” (8, p. 2). In addition to the fact that the students requested a supplemental session on scientific writing and citation, it has become clear to us that during this seminar, many of the students may have learned to conduct scientific research, write academically or professionally, and cite sources for the first time (S2.2, S3.2, S5.3). Regardless of whether they will go on to an academic career, it is nevertheless important to know how to conduct research, write professionally, and to demonstrate scientific integrity by citing sources.

### **Course Structure and Methods: Creative Freedom**

There were only four segments coded for creative freedom. Nevertheless, it stood out to us as a unique category worthy of investigation since it was an unexpected, recurrent theme among students' reflections. Furthermore, the three students who wrote about the creative freedom afforded by the ETs explained that this was unique to this seminar, and that they had not had a similar opportunity in their other courses. One student wrote, "I highly appreciate the creative freedom that we had for every examination task, from choosing our group work topic to structuring the essay... this creative freedom made this course special to me in terms of a learning experience," (3, p. 2). While these students agreed that they appreciated the creative freedom, two of them felt uncertain about what was being asked of them in the ETs and how they would be graded. Nonetheless, we maintain that creative freedom, wherever possible, allows students to explore more possibilities and adapt the assignments more to their own interests (S2.4). It provides a unique learning experience and opportunity. Furthermore, creative thinking is a skill rarely offered the chance to flourish in engineering programs. We speculate that interest in the course and creative freedom, among other factors, may have fostered deeper engagement and plans for lifelong learning.

### **Challenges and Misunderstandings**

Through the QCA of students' reflections, we discovered a few persistent challenges and misunderstandings that made it difficult for some students to develop the intended competencies. For example, one student expressed uncertainty as to "whether [they] should mostly concentrate on engineering itself or on ethics," (9, p. 2) when asked to ethically evaluate an example of AI in engineering, which unfortunately shows that some engineering students may be confused when faced with an interdisciplinary problem. With more exposure to interdisciplinary problems and courses, this apparent incongruence between technical and non-technical subjects should fade, replaced by interdisciplinary understanding (Wächter, 2011). Moreover, several students found applying the ethical principles to a real use case to be more difficult than initially expected. A student explained that "at first glance, the explanations [of the FAST and FACT ethical principles] seemed logical and simple. However, if you look more closely at the principles - which [they] did in Examination Task 2 - the consideration and especially the application to a particular case was more complex and difficult than expected," (12, p. 1). Meanwhile, two students misunderstood what the motivation for ethical AI should be. One of them explained that "the reality is that for technologies to be applied, the first predisposition is that they are profitable and that those responsible for their introduction are convinced of their benefits," (5, p. 2). While financial goals are often prioritized in industry, this is not the competency we tried to instill. It is important to be able to differentiate between business objectives and ethical ones in order to adequately balance the often-competing objectives. Some other concepts were at times also misunderstood by some students (e.g., the responsibility gap). Therefore, some students continued to struggle to understand the ethical concepts themselves and their interconnectedness with engineering topics, as well as how to apply this knowledge once it had been attained. We will take care to explain these difficult concepts more clearly in the future; however, some concepts are simply difficult to grasp when only introduced in one lecture. Many others agree (see Abate, 2011; Hess & Fore, 2018; Newberry, 2004) that students would benefit greatly from more interdisciplinary or multidisciplinary programs as opposed to a single elective, interdisciplinary course.

### **CDIO Standards 3.0**

While the CDIO Standards (Malmqvist et al., 2020a, 2020b) are meant to guide the implementation of an entire engineering program, we use them to evaluate the accordance of a single seminar (I&D) to the CDIO mission and its potential to act as an initial course introduced into an engineering program. Our hope is that our seminar would be followed by other courses that similarly meet these Standards as well as the Standards not covered by this seminar. Below, we demonstrate how the I&D seminar incorporates Standards 1, 2, 6, 7, 8, 11, 12, and Optional Standard 1.

According to the CDIO, engineers must be able to participate in each stage of the sustainable lifecycle of a product or service. They must be able to *conceive* of the customer and societal needs, *design* a solution to address this need, *implement* the design, and maintain the product or service during *operation*. Throughout the lifecycle, engineers must “understand the implications of technology on social, economic and environmental sustainability factors,” (Malmqvist et al., 2020a, p. 63). This (Standard 1: The Context) is precisely the mentality and awareness that the I&D seminar aims to cultivate in its engineering students.

In accordance with Standard 2: Learning Outcomes, the I&D seminar provides students with ample opportunity to (1) experiment with knowledge discovery via independent academic literature research, (2) develop critical and creative thinking when asked to come up with solutions to the ethical dilemmas they discovered in real examples of AI in engineering, (3) practice teamwork and communication (including in English as a foreign language), and (4) consider these applications in business, but particularly in societal contexts. Additionally, learning outcomes are announced at the beginning of each session along with expected levels of proficiency.

Standard 6: Engineering Learning Workspaces demands the combination of physical and digital learning environments. I&D was mostly conducted in a physical classroom, where lectures were given, students were provided with time and space to collaborate on group activities and discussions, and present ET3 at the end of the semester. There were also occasional online sessions for lecture and collaboration, in addition to the wealth of online resources provided via Moodle (an online education platform) including a platform for communication between group members. Nevertheless, some students wished for more dedicated time during the seminar for groupwork.

The I&D seminar is able to provide Integrated Learning Experiences (Standard 7) by teaching about applications of AI in engineering, clearly disciplinary issues, while simultaneously offering abundant opportunity to develop professional, personal, and interpersonal as well as sustainable product, process, and system building skills (see Standard 2) through the less traditional ETs. Students also found the course focus on real-world issues to be engaging. Thus, the ETs present professional engineering issues within contexts of disciplinary issues.

The seminar incorporates Active Learning (Standard 8) during the introductory lectures using class discussions, small-group activities, and individual reflection handouts (e.g., diversity dimensions handout). Several students articulated their enthusiasm for the course’s “interaction and liveliness,” (7, p. 2) as “the lectures were always structured in an interactive way, with regular questions asked to involve the students and help follow the lectures contents,” (10, p. 1). According to the students, this interactive style of teaching and learning is rare among engineering courses. Even so, other students expressed that they would have liked to have even *more* discussion during class since “[they] did not have that much time to debate

and discuss during the lecture time,” (9, p. 2). Students later practice experiential learning when they simulate the role of an AI ethics consultant for the AI in engineering case study their group chooses. The course thus “encouraged students to take a hands-on approach to apply ethical considerations of AI in their chosen domain,” (3, p. 2) when asked to ethically evaluate their chosen examples in the ETs. Several students lauded this practical training (of ethical evaluation) with real use cases.

Like most courses, the I&D seminar also includes Learning Assessments (Standard 11) of the students. However, in this case it is via four different portfolio ETs, each measuring a different set or level of the intended learning outcomes. Learning assessments are hence aligned with the stated learning goals.

The seminar includes Program Evaluation (Standard 12) via the students’ reflections (ET4) and instructor reflections and continuous revision of plans for improvement. For example, as part of this data analysis, we discovered instances in which the course could be improved based on the students’ feedback, and we have already implemented some of these changes in the seminar this year.

Finally, the seminar incorporates environmental and social sustainability (Optional Standard 1: Sustainable Development) within all CDIO Standards it covers (1, 2, 6, 7, 8, 11, and 12), especially since we define sustainability as a main theme of ethical AI applications in engineering. Furthermore, I&D fulfills UNESCO’s (2017) eight Key Competencies for Sustainability, which have been shown to map well to many CDIO Syllabus sections and was proposed as a basis to update the CDIO Syllabus to 3.0 (see Rosén et al., 2019). The normative competency is developed during introductory lectures on AI’s impact on society and AI ethics, as well as during the ETs, especially while ethically evaluating AI engineering applications for ET2. The collaboration competency is practiced via the groupwork required for ETs 1-3. Critical thinking, systems thinking, anticipatory, strategic, and integrated problem-solving competencies are all trained while completing ET2 and ET3 which entail a critical ethical evaluation of complex systems, applying the precautionary principle when anticipating possible outcomes, and considering integrated solutions that further ethical, and therefore sustainable, applications of AI in engineering. Lastly, self-awareness is practiced while writing a reflection paper for ET4.

## **CONCLUSION**

As a result of the seminar, one student summarized, “I now have a deeper appreciation for the importance of considering the ethical implications of AI and I am committed to using my skills and knowledge to contribute to the responsible and ethical development and use of these systems. So, I believe that this seminar has been a valuable learning experience that will be useful in my future career as an engineer working with artificial intelligence,” (16, p. 1). Through the seminar and ETs, students learn to think critically and creatively, discover the interconnections between engineering and other disciplines, and comprehend the positive and negative social and environmental impacts of an innovation such as AI. They use this newly acquired interdisciplinary understanding to address societal challenges and brainstorm possible solutions. The design of I&D’s portfolio ETs engage and enable students to acquire and develop personal, professional, and interpersonal skills and other competencies enumerated in the proposed CDIO Syllabus 3.0. Furthermore, at least some students subsequently accept their responsibility as engineers to society and to a sustainable, ethical future.

However, as with any research project, there are some limitations to our case study. First, we did not have the research idea in mind when we designed the course, so it was not designed in such a way as to maximize the usefulness of anonymized reflections and feedback from the students with respect to any specific research questions. To assess the learning outcomes of the students quantitatively, we must (and will) implement more explicit ethical AI competency assessment scales at the end of the course, especially since reflection papers likely suffer from social desirability bias. In addition, I&D is a single course rather than an entire engineering curriculum, which limits how much we can teach as well as the timespan of our investigations. This means we cannot be sure of students' competency retention and continued commitment to upholding ethical and sustainable standards in engineering applications. Nevertheless, our analysis should provide valuable insight into how an interdisciplinary course in engineering can be taught and how similar courses can contribute to educating future responsible engineers.

One student mirrored our “[belief that] RWTH University should offer more courses, like ‘Innovation and Diversity’, that go beyond technical and engineering subjects independent from the main study course implementing more multidisciplinary and ethical discussions,” (9, p. 2). Our hope is that our work will guide future attempts to restructure or introduce new courses to engineering curricula that engage engineering students in interdisciplinary topics while at the same time teaching the sustainability, interpersonal, and professional competencies that are now required of engineers.

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# LEVERAGING AI FOR EQUITABLE LEARNING: INSIGHTS FROM ACADEMICS IN ENGINEERING

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## ABSTRACT

Generative artificial intelligence is a hotly debated issue in the current landscape of educational research, with educators' abilities to utilise this powerful tool falling by the wayside as institutions focus instead on regulation. Current research on generative AI in engineering education, whilst in its infancy, places a large onus on studying students and how they use such services. Therefore, little is currently known regarding current and proposed uses of generative AI by engineering educators and academics. Its potential in enhancing educational methodologies often remains underexplored amidst regulatory concerns. This is especially true for the field of diversity, equity and inclusion where generative AI has been used in numerous ways to cultivate more equitable outcomes for engineering students. Our ongoing research aims to elucidate these current and proposed uses of AI to understand how it can be used to create equitable learning environments for undergraduate engineering students. This research aligns with CDIO Standards by investigating how generative AI can support active learning environments (CDIO Standard 8) and integrate diverse learning preferences into the engineering curriculum (CDIO Standard 7). Through a reflexive thematic analysis of six semi-structured interviews with academics from Monash University's Faculty of Engineering, the main themes of *Adaptive Integration*, *Balancing Efficiency with Deep Learning* and *Empowering Through Training and Resource Allocation* were discovered. Future research should centre around uncovering the mechanisms of algorithmic bias in the field of engineering, assessing the efficacy of generative AI powered pedagogical interventions in achieving equity, diversity and inclusion as well as the development of faculty scaffolded ethical guidelines and frameworks for the use of generative AI tools.

## KEYWORDS

Equity, Diversity, Inclusion, Artificial Intelligence, Standards: 7,8

## BACKGROUND AND MOTIVATION

Generative Artificial Intelligence (GAI) is not a new phenomenon but has entered almost all domains of common parlance due to its rapidly increasing sophistication in recent years. ChatGPT, one of the most prominent examples of GAI, represents this meteoric rise as it is now considered to be the fastest growing application in human history (Murugesan & Cherukuri, 2023). GAI, a technology that enables systems to 'think' and 'act' like humans, is not only defined by its ability to achieve goals and solve problems, but also embodies key advantages over other forms of artificial intelligence, such as its capacity for continual improvement of answers based on both current and previous user inputs (Akgün & Greenhow, 2022; Adamopoulou & Moussiades, 2020). With ever increasing catalogues of parameters within the LLMs that GAI interfaces are trained on, it is almost certain that GAI will touch most aspects of engineering education, revolutionising the field (Murugesan & Cherukuri, 2023; Johri, 2020; Bahroun et al., 2023). Within the community, calls have been made for initiative to be taken to both construct a knowledge base around its capabilities and use as well as documenting and shaping specific applications (Johri et al., 2023; Nikolic et al., 2023a).

In response, many tertiary institutions and researchers have immediately begun investigating concerns over academic integrity and engineering assessments, reflecting the broad interest and concern in this field (Nikolic et al., 2023a; Nikolic et al., 2023b; Abd-Elaal et al., 2022). Whilst this is critically important in ensuring the ongoing integrity of engineering assessments and by extension the quality of our future engineering graduates, this is not the first time that this tension has arisen. Necesal & Pospisil (2012) underscore a crucial decision for academics: one path involves prohibiting GAI tools, while the other entails integrating these tools into the educational toolkit. The latter being firmly in keeping with the philosophy of engineering wherein technological advances exist at its core, motivating the use of GAI tools in our learning and education into the future (Murugesan & Cherukuri, 2023). Consequently, GAI tools such as ChatGPT have been adopted in various educational settings with mixed results often overlooking their potential to enhance pedagogical strategies (Mollick & Mollick, 2023).

Implementation of GAI tools in engineering classrooms does not, however, come without just concerns. Issues of accessibility, bias, privacy and broader societal discrimination have been raised as such potential concerns due to GAI tools' abilities to widen already existing gaps (Akgün & Greenhow, 2022; Crutchley, 2021; Holstein & Doroudi, 2021; Menekse, 2023; Sun et al., 2023; Adamopoulou & Moussiades, 2020; Bobula, 2023). The concerns raised have significant socio-cultural implications, particularly in terms of equity, diversity and inclusion thus necessitating investigations into how these challenges can be effectively addressed in engineering education. This study follows the lead of many prominent engineering education research on equity, diversity and inclusion (EDI) in understanding EDI not as the sum of its component parts but rather as interlinking components that are co-dependent, inextricable from one another and are central to ethical engineering (Hess et al., 2023). In order to understand the interplay between GAI and EDI in engineering education researchers must be paradigmatically critical of the widely espoused and problematic notions of GAI tools being morally superior to humans due to their purported objectivity, neutrality and lack of bias in decision making (Crutchley, 2021).

This research, therefore, aims to understand the perspectives of engineering academics with regards to their readiness and willingness to incorporate GAI tools in their classes to support the principles of equity, diversity and inclusion. The subsequent reflexive thematic analysis is the product of six semi-structured interviews with engineering academics from a range of

departments and experience levels at Monash University. Ultimately, this research seeks to answer the following research question:

*What are the current perspectives of engineering academics regarding their readiness and willingness to adopt GAI tools to help achieve equity, diversity and inclusion in their classes?*

## LITERATURE REVIEW

The past year has seen a dramatic increase in the adoption of GAI tools both within engineering education and more generally (Murugesan & Cherukuri, 2023). Correspondingly, the body of literature on GAI in the field has followed a similar trend (Bahroun et al., 2023). This has understandably led to constraints on time for research to be published, leaving numerous unexplored and overlooked gaps in the current body of literature. This study aims to address a number of these gaps: it examines the integration of GAI into teaching pedagogies, highlights the need for academics and educators' perspectives in GAI discourse, investigates the benefits of GAI as an educational tool and addresses concerns about Equity, Diversity and Inclusion (EDI) in the context of GAI use.

Applications of GAI have been seen to, or have been espoused to have the potential to support the learning of students through various uses (Akgün & Greenhow, 2022). Potential benefits include the enhancing of personalised learning experiences, improvement of student engagement, autonomy and overall learning and achievement (Fatahi et al., 2023; Menekse, 2023; Mollick & Mollick, 2023; Nikolic et al., 2023b; Qadir, 2023). These benefits may be achieved through reducing the time delay and social barriers to receiving feedback, virtual simulations, low-stakes testing, improved writing skills as well as customised problem sets and learning opportunities (Fatahi et al., 2023; Menekse, 2023; Mollick & Mollick, 2023; Murugesan & Cherukuri, 2023). There is undeniable potential to transform students' learning through these practices, however, they are largely completed by students in isolation without being formally adopted by academics and scaffolded through their delivery of content and teaching pedagogy. This has the potential to be problematic for students' learning for many reasons such as the need for GAI outputs to be evaluated and curated by engineering educators to ensure their veracity (Menekse, 2023). Such scaffolding can free up time for educators to connect and engage with students on more complex engineering concepts with proposed areas of research also including the construction of lesson plans with the assistance of GAI tools (Murugesan & Cherukuri, 2023; Menekse, 2023; Budhwar et al., 2023). Academics are, however, largely overlooked in this process. Before the implementation of pedagogical interventions aimed at achieving the aforementioned espoused benefits of GAI tools, the academics who will bear the brunt of practically carrying out these actions must be consulted. This research primarily focuses on understanding how ready and willing academics and educators are to implement GAI tools in their classes.

There is a distinct lack of rich, qualitative inquiries focused on the views and lived experiences of key stakeholders involved with GAI adoption at the coalface of engineering education delivery, namely engineering education academics and educators. Much of the current body of research is focused on delineating the technical capabilities of GAI tools, investigating issues of academic and assessment integrity or theorising more philosophically on the concerns over how GAI tools will impact our future (Nikolic et al., 2023a; Nikolic et al., 2023b; Menekse, 2023; Murugesan & Cherukuri, 2023). In order to develop and improve the educational experiences and outcomes of our engineering graduates into the future we must however investigate how and why GAI tools should be adopted as well as who will be

responsible for these changes (Longo, 2020). It is for these reasons that this research focuses on engineering academics who will ultimately find themselves at the nexus of research and practice when it comes to GAI tools and engineering education. Deductive GAI tools currently lack the capacity to effectively interpret and utilise a swathe of nuanced qualitative information (Budhwar et al., 2023). Thus, further underscoring the importance of investigating the interactional relationship between humans and GAI tools, the complexity of which, is predicated heavily on deeply subjective and human forms of understanding. These centering around the readiness and willingness of engineering academics and educators to adopt GAI tools in their classes for the purposes of this research.

The ethical and moral concerns shared by academics and researchers regarding the potential for GAI tools to exacerbate existing social inequalities raises questions regarding the principles of equity, diversity and inclusion. These concerns include privacy issues, systemic bias perpetuation, historical and institutionalised bias as well as misleading and incorrect information generation (Akgün & Greenhow, 2022; Crutchley, 2021; Holstein & Doroudi, 2021; Menekse, 2023; Mollick & Mollick, 2023; Murugesan & Cherukuri, 2023). Together, such concerns are often referred to as algorithmic bias wherein the LLMs associated with GAI tools are trained on current and historic datasets, in turn further perpetuating and reflecting inherent societal biases (Akgün & Greenhow, 2022). In essence, GAI tools are only as good as the data on which they are trained and if adopted in a haphazard manner have the potential to further cement biases such as socioeconomic status, gender and race at an increasing pace (Qadir, 2023; Johri, 2020). Such algorithmic bias is present in numerous examples such as the study conducted by Sun et al., (2023) in which the GAI image generator DALLE 2 was shown to underrepresent women in male-dominated fields whilst overrepresenting them in female-dominated fields when studying occupation-based outputs. Furthermore, women were disproportionately depicted with smiles and downward-pitching heads when compared to generated images of male professionals, further sounding alarm bells with regards to the overt and unquestionable representational and presentational bias inherent in GAI tools. Such examples help to abolish the misguided notions of GAI as the embodiment of neutrality, somehow impervious to 'human' attributes of subjectivity and bias. The additional concern with biased datasets relates to the fact that GAI tools do not operate in isolation but rather construct the very datasets which they are themselves shaped by, ultimately exacerbating existing bias in an uncontrolled manner (Akgün & Greenhow, 2022). It must be acknowledged that our current and historic datasets are indeed problematic, both in forms that we are aware of and ones that we are not, if we are to effectively address issues related to EDI in our field (Crutchley, 2021). Therefore, as a research community we must first understand the perceptions and readiness of academics in engineering regarding GAI, algorithmic bias, and EDI concerns. Such understanding is fundamental in fostering a more inclusive and equitable engineering community. This is especially vital given engineering's historical challenges with representation, marginalisation and cultural issues (Holstein & Doroudi, 2021, Davis et al., 2023; Garriott et al., 2023; Küskü et al., 2007; Lohan & Faulkner, 2004).

In order to address the identified literature gaps and understand engineering academics' readiness and willingness to incorporate GAI tools in their classes to support the principles of EDI, the study employed a qualitative, reflexive thematic analysis as described by Braun & Clark (2013).

## METHODOLOGY AND METHODS

The methodological coherence and strength of any qualitative research is predicated on numerous factors including the clarity of the authors' epistemological and ontological stances which has been commonly overlooked in many engineering education research (Malmi et al., 2018; Bernhard & Baillie, 2013; Case & Light, 2011; Baillie & Douglas, 2014). This study applied a constructivist lens of enquiry in order to acknowledge the multiple, constructed and perceived realities of our study participants whereby there is no one objective and absolute truth to be discovered (Patton, 2002). In this sense, this study seeks to construct knowledge about the perceived reality of our participants rather than constructing reality itself (Patton, 2002). Our constructivist epistemology is consequently underpinned by an ontologically relativist stance wherein research participants are co-constructors of multiple subjective realities (Charmaz, 2014; Denzin & Lincoln, 2005).

The application of our stated epistemological and ontological paradigms motivated the use of semi-structured intensive interviews with participants. Such interviews firmly ground the interviewer within the process of constructing and co-constructing understandings generated from these interviews and acknowledge the interviewer as a valid instrument in the process (Charmaz, 2014). Intensive semi-structured interviews offer the researcher flexibility in following hunches during interviews to follow up on unanticipated avenues of inquiry, ultimately creating an interactional space that enables participants to effectively relate their experiences (Vander Linden & Palmieri, 2023; Charmaz, 2014).

The authors conducted 6 such interviews that were limited to approximately 45 minutes each due to constraints on participants' time. The interview questions focused on exploring the integration and impact of generative AI in educational settings and structured to encourage detailed responses. They covered a range of topics including the use of AI in teaching roles, its potential to enhance fairness and inclusivity in education, and the role of AI in creating and modifying educational content to address biases. They allowed the interviewees to reflect on their personal and professional growth, challenges faced in their academic careers, and their vision for the future of education.

Maximum variation sampling was carried out to select these 6 study participants. This is a non-probability sampling method that seeks to engage participants who vary on certain characteristics or traits in order to embed complexity within the study through eliciting multiple perspectives (Creswell, 2014). Such a method of sampling intends to represent the study population itself rather than being immediately and widely generalisable (Cohen et al., 2007). As such we selected a number of academics from a range of departments, levels of teaching experience and types of classes taught as can be seen in table 1 below.

Table 1. Summary of Study Participants

|             | Department                      | Position            |
|-------------|---------------------------------|---------------------|
| Academic #1 | Electrical and Computer Systems | Associate Professor |
| Academic #2 | Electrical and Computer Systems | Teaching Fellow     |
| Academic #3 | Mechanical and Aerospace        | Senior Lecturer     |
| Academic #4 | Mechanical and Aerospace        | Senior Lecturer     |
| Academic #5 | Civil                           | Lecturer            |
| Academic #6 | Chemical                        | Senior Lecturer     |

Thematic analysis is a systematic research design that is widely used in qualitative inquiry designed to identify and organise patterns of meaning in order to gain insights from data sets (Braun & Clarke, 2012). Such patterns of meaning are commonly referred to as themes which distil commonalities of meaning regarding how a certain topic is considered (e.g. how it is written about or spoken about) (Braun & Clarke, 2012). Thematic analysis is a flexible tool which can be applied to numerous studies and data sets. Braun & Clarke (2006) pioneered what is now known as reflexive thematic analysis which includes six steps of: familiarising yourself with your data, generating initial codes, searching for themes, reviewing themes, defining and naming themes and finally producing the report. This method of thematic analysis is associated with numerous advantages including producing accessible results, being participatory with respect to collaborators, offers a 'thick description' of dense data sets and is well placed to provide unanticipated insights (Braun & Clarke, 2006). As such, an inductive reflexive thematic analysis research design was chosen for this study, allowing emergent themes to be discovered in an interpretive manner that certain codebook and coding reliability approaches to thematic analysis can constrain through their relative rigidity (Braun & Clarke, 2021).

Transcripts of interview recordings were coded by the first author using NVivo 14 software with the final stages of reviewing, defining and naming themes occurring through consultation and conversation between the authors. This process of consultation was not enacted to achieve the more positivist notion of quantitative inter coder reliability but rather to elicit as much meaning and different perspectives from the initial codes and emergent themes to enhance the richness of our reflexive thematic analysis.

## **RESULTS AND DISCUSSION**

Our data analysis process consequently led to the generation of three overarching themes of *Adaptive Integration*, *Balancing Efficiency with Deep Learning* and *Empowerment Through Training and Resource Allocation*. These themes are outlined and detailed individually in the following discussion.

### ***Adaptive Integration***

Academics were often emphasising the need for AI to be adaptable to diverse cultural and institutional contexts, highlighting the importance of understanding and adjusting to various educational environments and student needs.

#### *Culture and Institutions*

Issues of adaptability to and access across diverse cultures and institutions was prominent throughout our analysis, posing great concerns regarding the equitability of GAI tools locally, regionally and globally. Opinions varied somewhat on the broader issue of accessibility from “*I don't see it [as] something that is as inequitable as many things in society*” to participants expressing their concerns on a larger scale as “*it would definitely create a bit of a divide if you think worldwide... there are many many places where students still rely on books*”. Global digital inequalities are ever present in our modernised world, impacting on educational outcomes and struggles for gender equality amongst other inequalities thereby supporting this latter contention (Ragnedda & Gladkova, 2020). Economic capital, a well-known determinant of technology adoption in educational settings was, however, a recurrent theme in many of these discussions with discourse generally centering around equality of access not being

possible “*if there’s a cost involved*” (Warschauer & Matuchniak, 2010; Warschauer et al., 2004). This exemplifies the broader socio-cultural concerns of academics regarding equity of access to GAI tools, necessitating further analysis of cultural adoption considerations. “*There are going to be cultural determinants of outcomes. I can see, for example, it playing very differently in an American university setting to, say, a Chinese university setting to an Australian or New Zealand university setting because the cultures are different*” mused one of the participants when questioned about the existence of any divides relating to potential advantages garnered by particular groups. This sentiment was shared by other participants who indicated that “*different universities, different places [and] people have different levels of technology absorption*” where certain Australian universities may not have expectations of personal interaction with their academics compared to an “*American college where you typically have many more personal conversations with a lecturer*”. These sentiments are supported in academic literature and really speak to the importance of avoiding any ‘one size fits all’ objectively ‘correct’ applications of GAI tools in teaching pedagogies (Hofstede, 1986). Cultures, institutions and students have vital, fundamental differences that need to be considered when choosing how to integrate GAI tools into varied settings as to not disproportionately advantage any setting or group of students over another.

### *Flexibility and Adaptability*

Such differences are myriad and infinitely complex, thereby motivating flexibility and adaptability of GAI use by academics and students to achieve their intended learning outcomes. This is compounded by the innate variability of GAI tools as is exemplified in the following participant quotation “*What ChatGPT was good at in January is not the same thing as March... So, the really key thing to teach is almost adaptability*”. This is a critical point as it extends the concept of adaptability and flexibility to something that not only affects the decision making of academics but something that also needs to be taught to students (Jonker et al., 2020). Each student has unique needs and our analysis indicates that academics want to empower their students to use GAI tools in personalised ways that help tailor their own learning placing GAI tools as a filter of sorts between academics and students.

### *Educational Environments and Student Needs*

When used as an intermediary between academics and students, educational environments may be tailored to students needs in a variety of ways. This has been seen to be absolutely critical, as is expressed by multiple participants as “*Some differently abled people I’ve run across really appreciate having resources delivered to them in their own environments*”. Tailored lecture notes, lecture transcription services, individualised assessment and differentiated content delivery were all raised by our participants as benefits of using GAI tools to meet different student needs and requirements as is consistent with literature (Pal, 2009). Using GAI to help improve writing and English skills of non-native English speakers was the most prominent benefit proposed. Participants saw GAI tools as “*an infinite source[s] of consultation*” where students of all levels of English proficiency, but particularly those who are non-native speakers, by allowing them to “*run [their writing] through gen AI to tidy it up and then compare with their initial version... until their brain starts to pick up those patterns themselves*”. These iterations lower the barriers to students seeking feedback on their work due to the non-judgemental nature of asking a chatbot or similar tool a question as opposed to an academic or teaching associate who may judge them for the quality of their work. As one participant states “*You have this very peachy view of yourself like, oh, I’m very approachable...but of course that doesn’t mean that they won’t be [scared of approaching an academic]*” in doing so, suggesting that just saying that students should feel free to approach



teaching staff is not enough. Students, especially from minority identities in engineering, can very easily feel intimidated approaching say a white man who is considerably older than them and in a direct position of authority (White, 2011). Harnessing and fostering students' *"willingness to interrogate gen AI, show it their work, and ask for general feedback"* in addition to shaping their own learning environments based on their specific needs presents itself as a huge opportunity to increase the equity, diversity and inclusiveness of engineering education environments yet there remains a balancing act between efficiency and deep learning.

### ***Balancing Efficiency with Deep Learning***

Balancing efficiency with deep learning was a prominent theme, acknowledging the efficiency and practical applications of AI in education, while being aware of its limitations in fostering deep learning, critical thinking, and creativity.

#### *Efficiency Gains*

The prevailing lens through which our participants viewed the future of GAI was that *"there will always be a human element involved [in education]"* but at the same time GAI tools are here to stay and educators *"cannot run away from it, otherwise we will all become obsolete"* leading numerous discussions on how to maximise efficiency gains. This is both in terms of educational delivery as well as student learning as one participant simply put it *"does it improve the quality of the output that [the students] produce. Yes, it does."* Improved student efficiency in getting more fundamental and broad guidance from GAI tools was also seen to have a knock-on effect for academics as if they *"have more time to dedicate to students... often students with EDI factors who need more support [and] guidance... I think that could even be a positive change"*. This efficiency gain can be realised through using the aforementioned freed up time to spend more time with students on *"high value interactions"* rather than *"spending human time doing dumb tasks"* or *"grunt work"* as this is required for higher-level work (Ismailov, 2022). Aside from this, GAI tools were used widely to perform certain teaching related administrative tasks on a *"superficial level"* including *"tidying up emails or announcements... generating communications"* that have certain formatting or structural requirements. Additionally, our participants spoke to GAI's ability to streamline their brainstorming processes on a wide variety of tasks and activities including *"brainstorming ideas, for example, project assessments... ideas on what we could do in the EDI space in terms of an event"* and coming *"up with some project ideas and a rubric as well"* which is consistent with contemporary literature on brainstorming (Lavrič & Škraba, 2023). In terms of assessment, participants indicated GAI's potential utility in generating multiple choice questions, helping students write reports to a rubric and with their professional writing. Ultimately these avenues of efficiency gains hold great potential in allowing academics and educators to spend more valuable time with students, especially those who may be differently abled or require additional assistance. However, such gains must be considered in conjunction with potential threats to students' deep learning, critical thinking and creativity.

#### *Opportunities and Threats to Deep Learning*

There was much trepidation over the impact of GAI tools on students' depth of learning and understanding with participants speaking to the potential benefits of their use but *"in terms of [improving] their understanding, I'm not sure"*. This stems from a sense of scepticism over the role that GAI tools can play in the knowledge transfer process as a *"shortcut"* of sorts *"that it isn't as deeply rooted as when that information is taken in by like different ways. Slower ways reading something. Discussing the finer points"*. This assertion is bolstered by numerous

participants who also indicated that the current lack of sophistication of GAI tools is a hugely limiting factor on their willingness to use them in their classes, something that has been raised with regards to AI's technical skills (Nikolic et al., 2023a). Proposed means of tempering such surface level learning include encouraging students to engage in the critical analysis of GAI outputs. As one participant noted *"I'm able to view [GAI outputs] and go, this isn't particularly useful, this is quite useful, and so forth"* indicating how they believe GAI tools are to be used as well as warning students that *"it often tells you things that aren't right or it can't justify it's answers."* A further concern that was expressed was that participants generally found that it is *"students who are struggling and who would really benefit from these tools aren't sufficiently engaged to actually realise there's an opportunity [to help themselves]"* and instead rely on GAI tools as a crutch rather than a tool or as another participant put it *"its showing, perhaps, a lack of willingness to engage critically with some tasks"*. To avoid this tendency, students need to instead engage critically by *"having a discussion about why its wrong, if its wrong"* ultimately encouraging students to use GAI in a *"proactive way around challenging the assumptions [of GAI tools]"*. In a similar vein, the theme of critiquing and challenging GAI outputs was also extended to questioning algorithmic bias by some participants. Put simply, *"its much easier to call a computer racist than a human"* largely due to the lack of power that GAI tools have over students as opposed to say their bosses or lecturers. This points to how engaging with GAI outputs critically can actually be an empowering force for social change and potential bias reduction within our field. Many participants also mentioned the potential to enhance student creativity as GAI tools can allows students *"to be more creative on complex things... because basic things were too time consuming or too energy consuming"* as well as *"explore their creativity a lot more than what they have now."* Despite concerns to the quality of learning of engineering students with additional use of GAI tools, through engagement with critical analysis of its outputs and creativity, there is great potential to enhance the deep learning of our engineering students whilst maximising the efficiency gains associated with GAI use.

### ***Empowering Through Training and Resource Allocation***

Training and resource allocation centres around the importance of providing adequate resources, training, and guidelines to empower educators and students to effectively utilise AI in a way that enhances learning and maintains ethical standards.

#### *Training and Resource Allocation*

Educators and students require adequate training and resources regarding GAI tools in order to truly harness the potential of such tools. Currently, uptake of GAI tools by academics seems to be largely dependent on personal gains as *"not everyone is motivated by benefits to the students. It'll be benefits to [academic's] personal circumstances"*. This is understandable given the rapidly evolving nature of such tools that requires academics to participate in *"constant active engagement"* even *"during the delivery of the course"*. Both points speak to the lack of time within academics' schedules to truly engage with and learn about GAI tools as one participant highlighted *"given my busy teaching and research role, I mean I would love to just sit down and muck around with chat GPT... and I'll be honest, I do not have time to do it."* This was a strong theme throughout the study, and is consistent with findings in current literature, as academics instead relied on other informal methods of learning about GAI tools such as peer learning and informal workshops put on by colleagues (Vinichenko et al., 2020). Solutions to address this largely involved structured approaches to GAI education both in the curriculum and in a policy sense. Calls were therefore made for GAI tools to become integrated into the *"ecosystem of our teaching"* with the need for *"training and a framework, a [set of] guidelines"*. Structured approaches to training and resource allocation that harness informal

learning networks are sorely needed in the field of engineering education that also acknowledge the importance of affording academics the time required to engage with GAI tools.

### *Ethical Concerns and Standards*

Such structured frameworks for GAI use must be underpinned by certain ethical and moral standards, many of which were raised as concerns by our participants. Concerns regarding embedded bias were in-line with those discussed in the previous literature review as a common sentiment amongst participants was *“if its being trained on real world data, the biases of the real world come in.”* Concerns included issues of gender bias as *“if it is fed that men are engineers and men author all the papers in engineering... then what does that say about our workforce”* in addition to racial bias for instance regarding *“our knowledge about traditional owners, traditional custodians of water ways... none of that stuff is really brought into a [GAI] model.”* Both quotations amplify the concerns over GAI models *“regressing to the mean”* and ignoring marginalised individuals, communities and ways of knowing, further pushing them to the margins of society. In essence, our participants spoke to a larger issue of centralization of knowledge as a result of widespread GAI use that repackages existing data, relating to the majority, as opposed to generating new knowledge as is encapsulated in the following quotation *“When you start using AI more heavily it is just going to be repackaging and regurgitating stuff that’s already there... there’s a risk that you might no longer be at the forefront, right? Because that requires some human discretion.”* Ethical guidelines and frameworks must also help academics avoid the overuse of GAI tools in student interactions, using them for smart automation rather than having students being *“palmed off onto something cheap”* and suffering from a *“telephone menu effect”* of sorts when students really need and expect a human to human interaction. Moving forward we need to start developing such ethical guidelines and frameworks for GAI use otherwise we risk worsening societal marginalisation, knowledge stagnation and lower student engagement and satisfaction.

## **CONCLUSION**

This study represents the first step in understanding the readiness and willingness of engineering academics to implement GAI tools in their classes to achieve the goals of EDI. Whilst many of our participants were largely unaware of any specific pedagogical uses of such tools, their perspectives are instrumental in illuminating potential concerns regarding GAI implementation as well as the factors that would enable them to use GAI in the future. Our reflexive thematic analysis of six participant semi-structured interviews revealed three main themes of *Adaptive Integration, Balancing Efficiency and Deep Learning* and finally *Empowering Through Training and Resource Allocation*. Future research should seek to delineate the mechanisms of algorithmic bias within the field of engineering as to better understand how to reduce such biases in engineering programs. Further investigation is also required regarding scholarship of teaching and learning in instances where GAI tools have been scaffolded into engineering classes as to illuminate its efficacy in addressing the goals of EDI. This study further motivates the application of qualitative research methodologies in a largely quantitative field in order to truly understand the perspectives of engineering education stakeholders at the coal face of teaching and learning. We encourage institutional leaders to be proactive in not only scaffolding GAI training for academics and students, but also in constructing guiding ethical frameworks and guidelines for the use of GAI tools to avoid myriad concerns discussed in this study.

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# **DISTINCTLY HUMAN - STUDENTS' PERCEPTION OF TRANSVERSAL SKILLS IN ENGINEERING CURRICULUM**

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## **ABSTRACT**

Through their participation in accreditation procedures, engineering educators are well versed in documenting transversal skills addressed by individual courses and across programs. But to what extent do students perceive support for the transversal skills that interest them? The student perspective is important to assess the curriculum as experienced by students but also because students' perception of what is taught is related to what they actually learn. Recent reports from our institution found that course documents fell short of institutional goals for transversal skill development and what graduates wanted skill development. While changes are still being implemented, this survey investigates students' current experiences. We asked 244 Bachelor and Masters engineering students about the transversal skills they encountered in the fall 2023 semester. Guided by the CDIO syllabus, we coded students' open-ended responses about the transversal skills they were most interested in developing and those for which they received the least support to develop. All three categories of transversal skills were found in students' responses, while disciplinary or technical skills were completely absent. This shows that transversal skills are understood by students. Skills from the category Interpersonal skills: Teamwork and Communication were cited most often both for interest (46% of responses) and for lack of support (45% of responses). The CDIO syllabus categories of Personal and professional skills and the Innovation process were also well represented. Using chi-squared tests with a resampling approach, our findings indicate that students do not perceive adequate support to develop the skills they prioritise. Our study suggests that the increased attention to developing engineering students' transversal skills is not yet sufficient. Frameworks and resources that support teachers to incorporate skill development in their courses are an important element in ensuring students receive the explicit and scaffolded instruction they need to develop these important skills.

## **KEYWORDS**

Transversal skills, Perceived curriculum, Engineering education, Standards: 3, 12



## INTRODUCTION

Current and future engineering students are tasked with challenges that will require them to master skills beyond the technical skills that traditionally represent an engineer's toolkit. They are expected to accomplish lofty and difficult targets such as the goals for sustainable development proposed by the United Nations (UN, 2015), or the Grand Challenges for Engineering proposed by the National Academy of Engineering (NAE, 2017). In this changing landscape of the engineering profession, engineers are expected to deal with complex societal and environmental issues while working in multidisciplinary teams and often in global contexts. Addressing global challenges like climate change, sustainability, and ethical issues will require a broad skill set that includes transversal skills such as ethical reasoning, global awareness, and the ability to work across cultural and disciplinary boundaries. Students are aware of the importance of developing transversal skills for their future careers (Direito et al., 2014; Donald et al., 2019) and also concerned about their current skill level (Direito et al., 2012; Lermigeaux-Sarrade et al., 2021). This paper uses the CDIO curriculum to categorise the transversal skills that most interest students and those students think they need most assistance to achieve their desired proficiency.

It is difficult to overstate the importance of transversal skills. In addition to being an important aspect of the engineer's toolkit, the development of transversal skills has been shown to predict students' success in later life (Heckman & Kautz, 2012). Additionally, employers increasingly emphasise the need for graduates who are more than just technically competent but also adept at communication, collaboration, and creative problem-solving (Craps et al., 2022; Patacsil & Tablatin, 2017; Robles, 2012; Succi & Canovi, 2020). However, multiple studies have highlighted the lack of work-readiness in current graduates (Busteed, 2014; Hirudayaraj et al., 2021; Patacsil & Tablatin, 2017). Studies that explored alumni perceptions of their engineering education found that while most were highly satisfied with technical and research skills, they were much less satisfied with the transversal skills they had gained and reported needing to fill in professional gaps especially in transversal skills such as 'project management', 'communication', and 'organisation' (Brunhaver et al., 2018; Kovacs, Capdevila, et al., 2023).

### ***Transversal Skills in Contemporary Engineering Curricula***

It is widely accepted that a comprehensive engineering education, that ensures that engineering graduates are "ready to engineer" (Crawley et al., 2007), should develop transversal skills along with developing knowledge and skills relating to core disciplinary concepts in engineering (Kolmos & Holgaard, 2019; Passow & Passow, 2017; Winberg et al., 2020). Recognising this, the development of professional or transversal skills is required by multiple engineering accreditation bodies both in Europe (Commission des titres d'ingénieur, 2023; European Network for Accreditation of Engineering Education, 2023), and at the international level (Accreditation Board for Engineering and Technology, 2023).

Focus on interpersonal and intrapersonal skills also forms an important part of the CDIO syllabus (Crawley et al., 2007). These skills, along with disciplinary knowledge and skills, are considered to be the building blocks necessary to thoroughly train engineering students. The 2.0 version of the CDIO syllabus highlighted the importance of ethics and equity as important components of intrapersonal skills (Crawley et al., 2011). This version also extended the CDIO ("Conceiving, Designing, Implementing, and Operating Systems in the Enterprise, Societal and Environmental Context") aspect to include leadership and entrepreneurship.

Despite the widely acknowledged importance of transversal skills, curricular uptake and change has been slow. A recent study at our institution (a mid-sized western European university) analysed course documents to ascertain the degree to which transversal skills were integrated into the curriculum, and found that the teaching of transversal skills fell short of institutional goals and accreditation ideals (Kovacs et al., 2020). In response, the institution launched several initiatives to address the issue and assist both teachers in transversal skill integration and students in transversal skill development.

### ***The 3T PLAY Trident Framework for Teaching Transversal Skills***

One of the major initiatives is the 3T PLAY project which focuses on providing resources to assist teachers in technical universities develop students' transversal skills using tangible objects. A major output from this project is the 3T PLAY trident (Fig. 1). This framework assists instructors to identify the three important aspects for the design of activities developing transversal skills - i.e. **Knowing** (what is the skill, why it is important, and what strategies can be employed), **Experiencing** (engaging activities that intentionally leverage the skill), and **Learning from Experience** (explicit reflection prompts to help students transfer what they learned to their next project). The improved understanding of the skills students perceive needing more support to develop provided by this paper is relevant for instructors and institutions to decide which skills should be the focus of such activities.

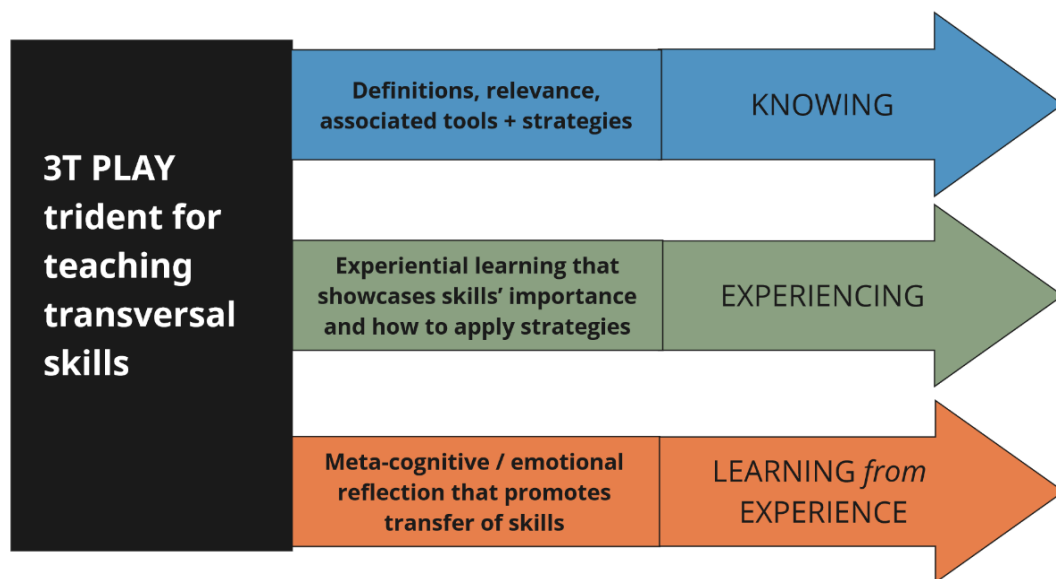


Figure 1. The 3T PLAY trident framework.

### ***Research Questions***

The context of our institutional efforts to develop transversal skills reflects the experience of many engineering schools. As mentioned above, our institution implemented several strategies including requiring instructors to state the transversal skills addressed by their courses. Additionally, our recent accreditation process required documentation of transversal skills addressed by individual courses and across programs. Although transversal skills are now an explicit part of the “planned curriculum” (Kovacs, Milosevic, et al., 2023), this study focuses on the “experienced curriculum”.

Specifically, we ask:

- Which groups of transversal skills from the CDIO framework do students prioritise most highly?
- Which transversal skills do they perceive needing additional institutional help in developing?

## **METHODOLOGY**

### ***Settings and Participants***

The data was collected in a mid-sized European engineering institution. To improve academic outcomes in the first-year large enrolment courses, the institution has implemented several initiatives, including a training program for student teaching assistants who will be employed in these courses. These student teaching assistants, henceforth referred to as students, are typically senior Bachelor's and Master's students who are required to attend pedagogical training workshops. The survey was administered during one such training. The benefit of this opportunistic data sampling is that it provided a diverse sampling of students from across the institution.

### ***Data Collection & Analysis***

While the survey had additional Likert-style questions, this study focuses on two open ended questions that asked students:

- What are the 2 transversal skills that you are personally most interested in developing? (coded as Personally interested)
- What are the 2 transversal skills that you think EPFL students get the least support to develop? (coded as Least support)

This qualitative approach avoided limitations to assessing students' perceptions by imposing a list of skills and enabled a robust examination of students' conceptions of what 'transversal skills' should be developed in their programs. 217 students responded to the prompt about skills they were personally most interested in developing (n of responses = 447), and 200 students responded to the question about skills they got the least support in developing (n of responses = 440). Students' responses were terse, consisting of 2-3 words or a brief phrase and were coded using qualitative content analysis (Schreier, 2014) using *a priori* codes taken directly from the subsections of v2.0 of the CDIO syllabus (Crawley et al., 2011).

We used a chi-squared test of independence to evaluate whether responses that students listed as having 'least support' were also those in which they were most interested in developing. We quantified the strength of the relationship between the two categorical variables using Cramer's V. Because each student's response included multiple skills (multiple codes), the data contained hierarchical structure that the standard chi-squared test cannot account for. We therefore used a resampling approach to generate 1000 datasets that each contained one skill (code) from every student's response to the question about 'least support' and one skill (code) from their response to the question about which skill they were most interested in personally developing. We performed the chi-squared test on each of these 1000 resampled datasets, using 10000 Monte Carlo simulations for each test to calculate a p-value. We also calculated Cramer's V for all 1000 resampled datasets.

## RESULTS

### ***Students' Responses Clearly Map onto The CDIO Syllabus***

We found that the skills students mentioned mapped very clearly onto the sections and subsections of v2.0 of the CDIO syllabus (Fig. 2). These skills related to subsections of Section Two (Personal and Professional Skills and Attributes - shown in blue), Section Three (Interpersonal Skills: Teamwork and Communication - shown in yellow), and Section Four (Conceiving, Designing, Implementing, and Operating Systems in the Enterprise, Societal and Environmental Context – The Innovation Process - shown in red).

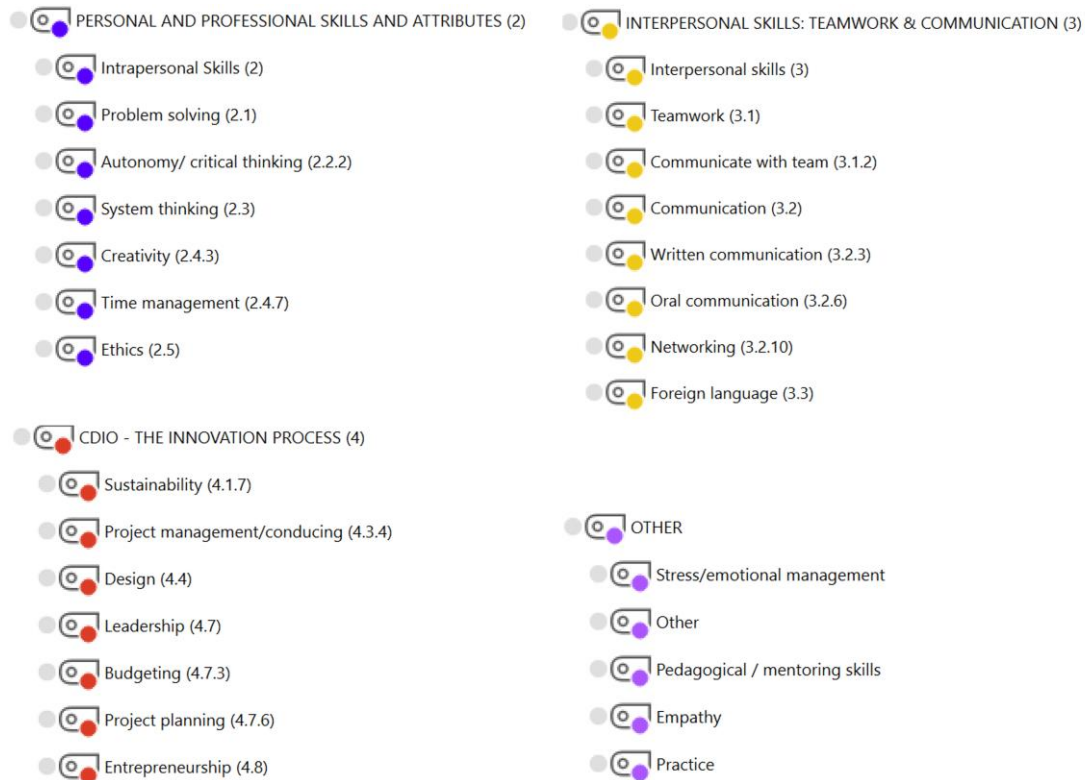


Figure 2. Coding scheme based on v2.0 of the CDIO syllabus (Crawley et al., 2011). Section and subsection numbers that correspond to the CDIO Syllabus for each code are given in the brackets.

The skills which could not be directly mapped onto the CDIO syllabus were put into the “Other” category (shown in purple). These included stress/emotional management, pedagogical/mentoring skills. Additionally, two students cited ‘empathy’ in response to both the prompts. Students’ responses did not include any ideas that would have been coded under Section One of the CDIO syllabus (Disciplinary Knowledge and Reasoning).

### ***Students Prioritise Interpersonal Skills***

Our data clearly shows that students prioritise Interpersonal skills: Teamwork and Communication (CDIO syllabus Section Three); this category both has the overall combined responses for both the prompts (46% and 45% of total responses for Personally develop and Least support respectively, Fig. 3), and contains the individual subcategory most frequently

cited for interest and lacking (Fig. 4). Within this category, students named “Communication”, “Interpersonal skills” and “Teamwork” as the skills that they would both like to personally develop and receive least institutional support in developing.

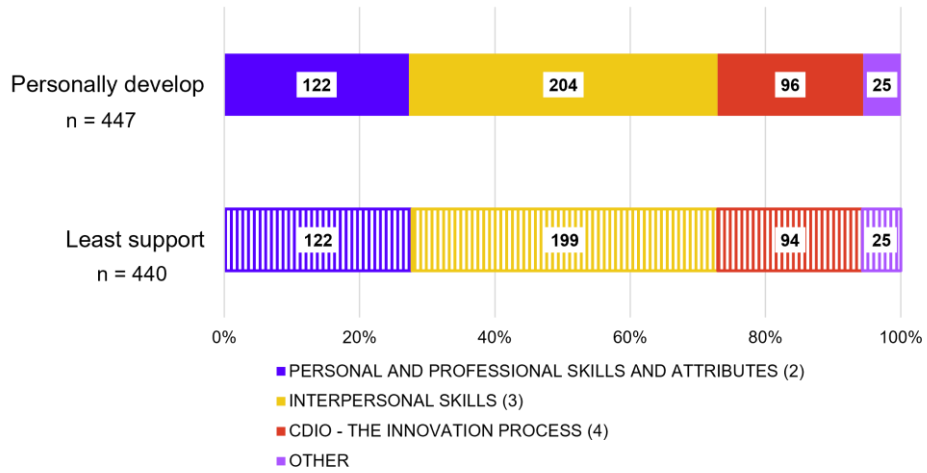


Figure 3. Relative frequencies of the groups of skills that students reported wanting to personally develop (solid-coloured bars) and getting least institutional support in developing (striped bars). Absolute frequencies are listed in the figure.

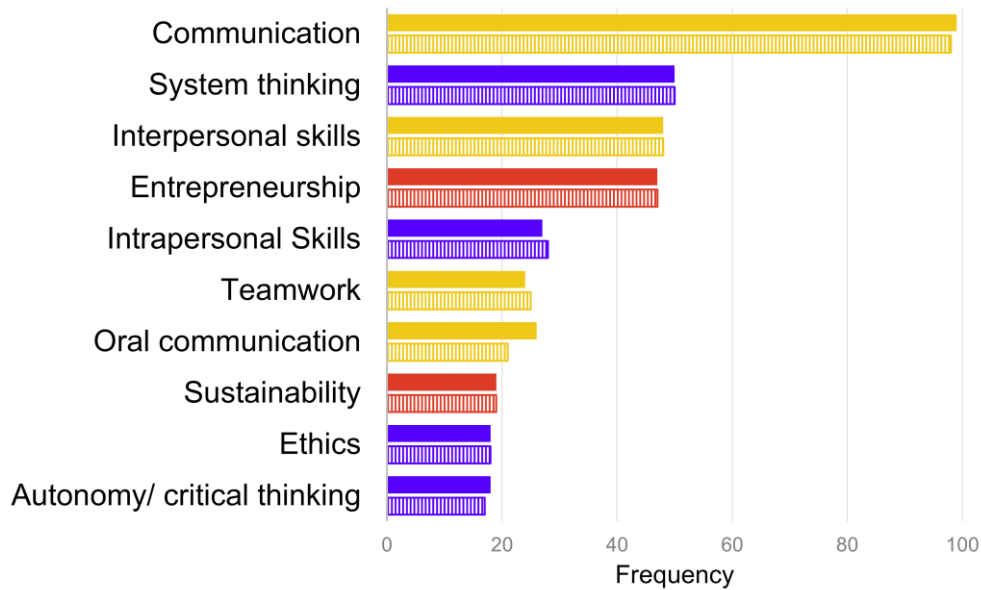


Figure 4. Number of responses for each of the top ten skills that students reported receiving least institutional support in developing (striped bars, total n of responses = 440). Solid bars indicate the number of students that said they wanted to personally develop (total n of responses = 447) that skill. The colours map on to the sections of the CDIO syllabus as seen in Figures 2 and 3.

Our data indicated that the next highest priority for students (27% and 28% of total responses for Personally develop and Least support respectively, Fig 3) were skills related to Personal and Professional Skills and Attributes (CDIO Syllabus Section Two), with special emphasis on “System thinking” and “Intrapersonal skills”. “Ethics” and “Critical thinking” (Fig.4). And finally, the skills of “Entrepreneurship” and “Sustainability” from Section Four of the CDIO syllabus also appeared in the top 10 list of skills that students both wanted to personally develop and reported receiving least institutional support (Fig. 4).

### ***Students Perceiving Needed Additional Institutional Support to Develop the Skills they Prioritise***

We found strong evidence that students are most interested in developing skills for which they believe they had the least support. Our analysis showed that the codes in the responses to the two prompts were not independent according to the chi-squared test of independence ( $p < 0.0001$  in all 1000 resampled datasets). We also found that the association between the responses was very strong (mean Cramer’s V = 0.65 [95% intervals of 0.60, 0.70], Fig. 5).

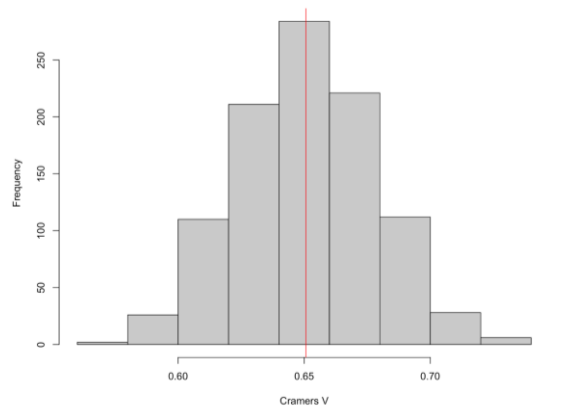


Figure 5. The distribution of Cramer’s V values across the 1000 resampled datasets. The vertical red line indicates the mean value of 0.65.

## **DISCUSSIONS AND CONCLUSIONS**

We chose to ask open-ended questions (qualitative data) in this study for two major reasons. First, we would not have been able to account for all the possible transversal skills in a quantitative framework. Second, and more importantly, we wanted to ascertain students’ perception of what they considered to be transversal skills and investigate any propensity to confound transversal skills with disciplinary skills or knowledge.

Our data showed that the CDIO framework is useful for teachers to reflect on the transversal skills that are present in the course. It is particularly interesting to note that students did not cite disciplinary or technical skills when asked about transversal skills. This shows that institutional messaging about transversal skills has been successful in creating shared language and understanding with students.

It is interesting that “Entrepreneurship”, “Sustainability” and “Ethics” are skills that students prioritise. While these were not included in the first version of the CDIO syllabus (Crawley et

al., 2007), they were included in the updated version of the syllabus based on reflections on the evolving roles of engineers (Crawley et al., 2011). Our data indicates that students have experienced the same evolution in thought processes as the syllabus designers and afford increased importance to these skills. It was additionally interesting that two students included empathy on the list of skills they prioritise. Developing empathetic engineers is indeed desirable, and engineering educators have proposed a model to foster the teaching and learning of empathy as a skill in engineering (Walther et al., 2017).

Importantly, our data shows that students both value transversal skills and would appreciate additional support in developing these skills. Previous studies found students have low self-efficacy for transversal skills (Direito et al., 2012). At our institution, in a study that explored Master's students' self-efficacy, almost a third of the respondents indicated having insufficient mastery in transversal skills like project management (Lermigeaux-Sarrade et al., 2021). They are clearly interested and ready to take advantage of additional support that is provided to them, and therefore teachers can expect to get warm welcome to integrating these aspects. Teachers should therefore leverage this opportunity to experiment and develop activities to respond, as they will benefit from good engagement. The CDIO syllabus in general, and the data from this study in particular, will help teachers identify and prioritise the skills they would like to focus on.

While teachers appreciate the importance of transversal skills and have explicitly included them in their engineering course syllabi (Kovacs et al., 2020), they see barriers to integrating them in their teaching and expect students to develop these skills simply by engaging in activities where they are needed (Isaac et al., 2023). This is especially evident in the fact that even though "Communication" was one of the skills that was listed with higher frequency in course syllabi (Kovacs et al., 2020), it was also the skill that was mentioned most often by the students as being a priority and as getting least support in developing.

Our study suggests that the increased attention to developing engineering students' transversal skills is not yet sufficient. Previous work suggests that this will require providing more support for teachers on how to incorporate opportunities for skill development in their courses to ensure students have the explicit and scaffolded instruction they need (Isaac et al., 2023; Kovacs, Capdevila, et al., 2023; Picard et al., 2022). We therefore present both the 3T Play trident framework (Fig. 1), and the associated activities developed by the team (See: Isaac & de Lima, 2024a, 2024b in 3T PLAY, 2024) to help teachers operationalise the development of these skills in their classrooms.

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## BIOGRAPHICAL INFORMATION

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# UTILIZATION OF THE DESIGN PROCESS FOR DEVELOPMENT OF A NEW PROGRAM CURRICULUM

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## ABSTRACT

Program curriculum development is a pivotal undertaking to ensure program relevance in a dynamic world. This paper focuses on utilizing a product development methodology to shape the next generation of the Industrial Design Engineering program. The methodology has emphasis on understanding the user and stakeholder needs to develop innovative program curriculum both efficiently and effectively. The primary research question addressed is: "How can a Product Development process be used for developing a new program syllabus?". Given the novelty of applying this methodology to university programs, our exploration sought to identify the most effective methods from the product development process. Initial steps involved gathering information about anticipated future scenarios to ensure the program's relevance, currency, and adaptability to changing landscapes. The program structure needed to accommodate dual-degree variants, allowing students to choose their major initially and later decide their degree path. This flexibility aimed to prepare students for the workforce or further studies, depending on their chosen path, after three years. Following the pre-study, iterations occurred through idea generation, evaluation, and cross-fertilization of drafts outlining the new design program's potential structure. Employed methods included surveys, trend analysis, brainstorming, brainwriting, Pugh's decision matrix, and PNI. The result was three distinct program structures, each offering students the option to complete their studies in three years or pursue a master's program. The final concept that was created after the final phase was completed is designed to not only keep students in sync with societal changes. The academic year and course structure is also organized to clarify each course's purpose and its relationship to others, fostering a cohesive learning experience. The adoption of a product development methodology for crafting a new program curriculum did not only prove to be successful but it also remained effective throughout the entire process. Last but not least the methodology also provided many new ideas on how a program curriculum could be structured.

## KEYWORDS

Product Development, Programme syllabus design, Standards: 1, 3, 4, 5.

## INTRODUCTION

To meet the ever-changing need from both students and society, including companies, our programmes at universities regularly need development. Chalmers University of Technology currently offers two variants of engineering education in industrial Design. Students have the option to pursue a Master of Science (MSc) in industrial Design Engineering (IDE) degree after five years of study after first completed a three-year Bachelor of Science (BS) degree, or a Bachelor of Science in Engineering (BSE) degree after three years and the option to take a MSc in Industrial Design Engineering master's degree. At Chalmers, it should be noted that a vast majority of the students from the BSE program continue with studies in a master in the same field, which basically creates two different routes to the 5-year MSc degree.

Since the first three years at the BS and BSE programs in IDE are very similar and the students should have the opportunity to choose whether to continue for a Master during their studies or exit after three years, we want to investigate how a new Industrial Design Engineering program can look like and we want to use a modern approach to develop this. The flexibility that the students can exit the program after 3 years will be a possible game changer for both the students as well as for the industry to adapt to the fast-changing world.

This development endeavour is considered crucial not only in ensuring the successful integration of the combined program, equipping students for both industry roles and advanced studies, but also in maintaining relevance and adaptability to evolving societal and technological trends.

Design methodologies have been used in different forms for product development in industry for many decades. The area is being researched e.g (Ulrich and Eppinger 2016). The methodology or Product development process comprise the following steps:

1. Customer needs identification and
2. Concept generation
3. Concept evaluation and selection
4. System and detailed design.

One of the most crucial things to include is the investigation of the customer needs (sometimes user) in this loop. Bringing all aspects to the table, keep an open mind and finally rather reduce the solutions which have many drawbacks than nominate one winning too early. The idea here is that this engineering principles could be used also for program curricula development.

### **Scope**

The purpose of the study is to explore, analyse, compare, and evaluate how the design program at Chalmers University of Technology, in the event of potential changes, can undergo the most positive development possible regarding program structure, content, collaboration, and adaptation to the constant evolution of the future. Additionally, it aims to provide results that can be utilized in similar endeavours for other subject specializations.

### **Research question**

The research question that has been in focus for the research is posted below.

- How can a Product Development process be used for developing a new program syllabus?

## THEORY

There are many papers describing new or partial program curricula, not at least in the CDIO context, e.g. Enelund, M. et al. 2012), but also with an IDE connection (Voûte, E. et. al. 2020), there are not many describing the recipe for a successful process to develop or reform a program. This might be because it is not of common interest to describe the process and the result is more important than the route. A program must of course fulfill national degree requirements but also local ones as well as fulfilling societal and industrial needs. The CDIO standards give good insight on what the result should look like and what the university wants with the program. On a high level, the principles for this are described by Malmqvist et. al. (2006). In this paper we apply a form of Product Development Process (PDP), described by many, e.g. (Ulrich and Eppinger (2016), as a means when developing a program syllabus and reflecting on its usability.

At Chalmers University of Technology, it is a standard to use the CDIO principles when designing programmes as well as courses Malmqvist et. al. (2010). In this case this means the standard 1 The Context is met by a clear Industrial Design Context throughout the programme taking the CDIO principles back to its roots. Standard 3: Integrated Curriculum even though we have not defined this specific course for each interpersonal skill we work with them on an overall level to have them in a course where they belong naturally. This is how we want the students to work in real life but also and not let them think these are separate subjects but rather integrated and therefore best taught in connection with other subjects. In accordance to Standard 4, there is an Introduction to Engineering course given as the first course at the program. In accordance to Standard 5 The curriculum includes two or more design-implement experiences, including one at a basic level and one at an advanced level.

### **Product Development**

Product development is the process of designing, creating, and marketing new products or services to meet the needs of customers. It involves several stages, including idea generation, product design, prototyping, testing, and launch. The goal of product development is to create products that are innovative, high-quality, and meet customer needs. There are several books and proposals for how to carry out product development. Ulrich and Eppinger (2016), provides a comprehensive overview of the product development process. It covers contemporary design and development issues, such as identifying customer needs, design for manufacturing, prototyping, and industrial design. It presents a set of step-by-step product development methodologies aimed at bringing together the marketing, design, and manufacturing functions of an enterprise. Cross (2023), provides an overview of the design thinking process and its application in product development. It covers topics such as design methods, creativity, and innovation. He presents a set of design thinking principles aimed at improving the effectiveness of product development

Ullman (2003) presents a comprehensive overview of the mechanical design process. It covers topics such as design methodology, conceptual design, and design for manufacturing. It presents a set of mechanical design principles aimed at improving the efficiency and effectiveness of product development

In this paper a general product development methodology has been proposed and used to create and evaluate different curriculum concepts. The strength of the product development methodology is that it starts with identifying the user needs (in this case the student, society,

industry need) and then creates and evaluates concepts upon these to come up with a final solution.

## CONDUCTED METHODOLOGY

In the following section the conducted methodology will be presented. The group that has carried out this work in line with the co-creation process, consisting of two design students, the head of Industrial design engineering and Mechanical engineering as well as the dean of education. This project setup afforded us the advantage of involving diverse stakeholders, thereby enhancing the relevance and accuracy of our outcomes. This approach also minimised the risk of overlooking crucial stakeholder perspectives during the initial phases where the prospect of adaptability persists (Ind, 2013).

### Process Initiation

The project began by creating two drafts of how a curriculum for the design program could be structured, see Figure 1 below. The initial draft was prepared the head of Industrial design engineering and Mechanical engineering as well as the dean of education, while the second draft was created by two design students. The decision to do this early in the project were because the student group members had not yet been influenced by various requirements and criteria that needed to be met. Another reason why these two drafts were created were due the fact that these later could be used to compare and evaluate the upcoming drafts (which you can read more about under “*evaluation and development of more realizable concepts*”). These drafts were also intended to highlight the differences before and after the implementation of the product development methodology.

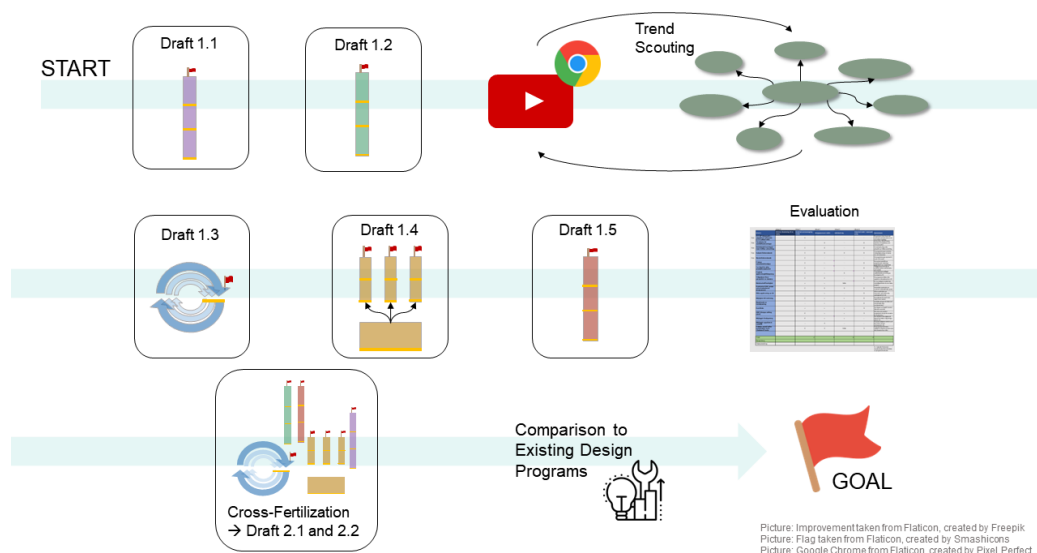


Figure 1. General overview of how the process unfolded.

## **Preliminary Study**

After the initial drafts were completed, an extensive trend scouting was conducted. The goal of the trend scouting was to formulate a foundation showing roughly the direction the future could take (within 20-30 years), thereby increasing the possibility of generating well-adapted program drafts later on. Areas explored during the trend scouting included future society, new technology, sustainability, social and economic aspects, the automotive industry, and more.

Based on the trend scouting, seven pillars were identified as the most significant for the potential lifestyle in 20-30 years. These were: sustainability, user perspective, distance and closeness, the ability to get what we ask for, digitalization, a greener society, and change.

To gain a deeper understanding of how the future development of the design and engineering profession could unfold, the decision was made to conduct additional information gathering, which was done in the same way as the earlier trend scouting. This new information would be used to formulate the foundational pillars for a future design program, serving as a valuable resource for the upcoming ideation. Through previous iterations, five pillars were formulated for a complete design program. All the pillars formulated during the preliminary study, would later form the basis for drafts 1.3, 1.4, and 1.5. In parallel with the trend scouting and information gathering, we used ChatGPT to investigate whether the conclusions that were drawn were somewhat consistent with the information compiled by ChatGPT.

During the same period, a survey was created and later distributed to the newly admitted students to the "design and product development (BSE)" and "industrial design engineering (BS)" programs at Chalmers in 2023. The survey questions were formulated to assess students' interest in technology and design, specific subjects they look forward to studying, and their attitude toward the titles "civilingenjör" and "högskoleingenjör". The results of the survey responses were then considered in the evaluation of the drafted proposals. Through the survey, the group could also identify students whose choices might have been different if they disregarded the titles ("högskoleingenjör," "civilingenjör"). Looking at the survey answers, we saw that the job title really matters when people choose their education. In fact, 92% said they picked their degree because of the title.

## **Idea Generation - Visionary Concepts**

After the information gathering and trend scouting were completed, and the information was compiled, the second phase where the actual ideation process began to develop more visionary concepts on how a new program plan could look was initiated. During this process, methods such as brainwriting and brainstorming were used to stimulate creativity and start sketching new concepts. Through the ideation process and discussions with the head of program for BSE and BS, three visionary drafts were formulated, drafts 1.3, 1.4, and 1.5 see figure 2 below.

Draft 1.3, which came to be called "The Design Process" was developed with inspiration from the structure of the design process and was built on four main areas: preliminary study, realisation, presentation, and context. The main purpose of the draft was for students to go through the entire design process in one year and then specialize in each element the following year.

Draft 1.4, which came to be called “Individual Path” was created through brainstorming and inspiration from the trend analysis and the structure of vocational colleges. The reason for the influence of the structure of vocational colleges was due to the aspect that in some areas, such as CAD, according to the trend scout, it will become more challenging to compete. This suggests that a thorough specialization in a subject can help students in the industry.

The final draft, draft 1.5, called “Integrated Mathematics” was developed based on draft 1.1 with the idea of dividing mathematics into smaller courses that naturally relate to other subjects. In this way, it can act as a tool for increased understanding while simultaneously highlighting its own purpose. To observe the structure of the different concepts, see figure 2 below.

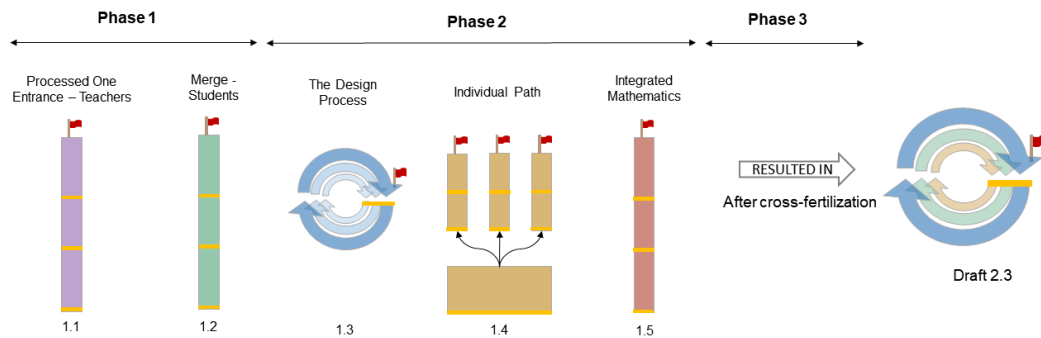


Figure 2. Displays the structure of the different program plans.

### **Evaluation and Development of More Realizable Concepts**

After the three more visionary drafts were created, the decision to begin the development of more achievable drafts was made. The first step to achieve this was to initiate the evaluation phase and formulate requirements that the upcoming drafts must meet and criteria that it is desirable for the drafts to meet. To know which criteria were more important and/or more desirable to be met, the group conducted a weighting of the various criteria through pairwise comparison. After the weighting was completed, Pugh's decision matrix was used to evaluate the different drafts with draft 1.1, as the reference draft. Pugh's matrix is a method commonly used for the evaluation and comparison of developed concepts. The purpose of the method is to facilitate decision-making and promote objective assessments in more complex choices. The process involves comparing the different concepts to a reference, and depending on whether the concepts meet the criteria better, worse, or equally well, which results in a total score in the end. By using this method, one can also more easily identify the strengths and weaknesses of each concept.

To complement the Pugh matrix, a PNI, which stands for “Positive Negative Interesting”, was also performed, highlighting more of the drafts' own characteristics rather than in relation to the reference. PNI, is also a method used to evaluate concepts. The purpose of the method is to identify positive, negative, and interesting aspects of each concept, serving as a basis for the development of new concepts. After the methods of Pugh's matrix and PNI were used to evaluate the concept, all materials were compiled together with a requirement list, which together formed a good foundation for the third and final phase of the process, which involved cross-fertilization of drafts 1.1–1.5. The purpose of cross-fertilization was to generate new, more achievable concepts, which were accomplished by combining ideas from previously



developed concepts. It was at this stage that thoughts previously formulated during the use of Pugh's matrix and PNI came into play, forming the basis for the development of more realizable drafts.

The cross-fertilization resulted in two more achievable drafts, 2.1 and 2.2 (second generation), which were later evaluated by us. As these were generated with consideration for values and requirements, they were deemed sufficiently developed to be compared with the existing design programs at Chalmers.

Therefore, this comparison between the second generation and the existing programs was made to ensure that nothing essential or successful had been lost during the process, and if so, it could be brought back. An investigation was also conducted on whether the second-generation drafts still provided eligibility for the master's programs that currently follow BS. After this comparison, drafts that were created in the second generation were further refined into a final program draft, which came to be called draft 2.3, see Figure 2.

## **RESULTS**

The use of the product development process as a method for the creation of new university programs curriculum is proved to yield positive results, as the developed programs were considered sufficiently elaborated and well-formulated to proceed to the next stage of implementation. The process structure, involving a preliminary study, iteration between idea generation and information gathering, as well as evaluation and cross-fertilization, demonstrated a systematic and logical progression of work.

The foundation laid during the initial studies provided a basis for the essential components of the program, influencing subsequent ideation towards program aims. Iterations between ideation and information gathering expanded perspectives and gave natural feedback to fill in gaps where information was lacking, without regressing in the process. The evaluation phase in the program development process identified areas where changes were needed in the more visionary programs, guiding the refinement and adjustment of the approach.

As mentioned earlier, each program was consciously endowed with distinct strengths and selling points to broaden the range of solutions. The cross-fertilization of program structures initiated towards the end of the process ensured that these diverse attributes were leveraged. The outcome was that programs with different themes broadened the perspective, and during the finalization of the last draft through cross-fertilization, all aspects could be considered. This resulted in a program customized from its parent programs—a thoroughly and accurately assembled outcome well-aligned with the goal.

## **DISCUSSION**

The utilization of a product development methodology for developing a university program curriculum felt intuitive and natural, yet this may not be applicable for individuals from different fields who wish to implement this approach. The cyclical nature of product development, with its feedback loops and emphasis on user experience, seamlessly aligned with the dynamic nature of academia. Each stage of the curriculum development process became a prototype,

subject to evaluation and enhancement, mirroring the iterative testing and improvement characteristic of successful product development cycles. The methodology's emphasis on adaptability and responsiveness to evolving trends and demands in education proved invaluable, resulting in a curriculum that felt not only comprehensive but also agile and well-suited to the ever-changing landscape of higher education.

### ***Selection of Methods***

The methods chosen for the process included trend scouting for pre-studies, dividing ideation into three phases (initiation, visionary and realizable), and employing PNI and a Pugh matrix for evaluation. The decision to initiate trend scouting was based on the program's goal of aligning with future changes in education and society. Acknowledging the unknown nature of the future, our approach needed to rely on well-formulated guesses derived from past events and future predictions.

Employing the trend scouting method enabled us to investigate current trends not only in industrial design engineering but also in related fields such as AI, technology, future cities, and evolving living standards. To maximize information within a brief timeframe, we consulted diverse sources, including YouTube, podcasts, and articles. Subsequently, ChatGPT was utilized, due to its time-efficiency, to validate our perspective and identify potential information gaps post-gathering. Highlighting these gaps allowed us to iterate the information gathering around these elements for a more detailed picture. This approach proved invaluable as the easily accessible platforms offered diverse search results, encompassing various perspectives, depths, angles, and expertise. The efficiency of this method likely allowed us to gather more information with different viewpoints and focuses than if we had relied solely on reading articles and papers. Overall, this method together with AI played a fundamental role in enhancing our understanding of potential crucial pillars for the future work of design engineers and the general human lifestyle.

Regarding the credibility of our primary source, YouTube, we recognise its challenges in terms of trust compared to other sources, as most channels lack transparency about personal perspectives, expertise, and sometimes even their own sources. Consequently, all information derived from our information gathering results is compiled based on consistent information from multiple videos, avoiding reliance on a single source. Prioritizing a broad information gathering approach, we considered this more significant than the sophistication of the sources' content.

The ideation part in the process was divided into three phases that each had different directions in the generation of programs. The first phase was centred around refinement and ideation on the own experience, while the second was more visionary and the third more focused on realisation. The methods mainly used was brainstorming, brainwriting and cross-fertilization.

The pivotal role in this project was played by the second ideation phase, where it was sought to craft more visionary and adventurous drafts. Here, brainstorming was fundamental, while brainwriting did not serve as well as with product development. Yet brainwriting was instead used to draw the general shape of the programs, for example as in figure 2. Employing this approach allowed for the exploration and expansion of potential solutions for varied program structures, a critical aspect in achieving a more futuristic orientation for the developed program. This phase involved a continuous questioning of "what if...?". Consequently, this stage served

as the bridge linking the formulated pillars from the pre-studies to the generation of well-defined program drafts.

Prior to the final ideation phase, the visionary concepts underwent evaluation using pairwise comparison, the Pugh matrix, and PNI methods. Conducting these assessments proved crucial, aiding in pinpointing strengths and weaknesses, as well as identifying shared and distinct traits among the drafts. This understanding was valuable as it enabled us to outline aims and necessary outcomes for the impending cross-fertilization method, proving to be a vital step in realising the programs.

The cross-fertilization, the primarily used method during the last phase for a more realistic combination of programs, complemented the prepared formulation of strengths and weaknesses for each program derived from the evaluation. The programs generated from this method ensured the fulfilment of all criteria in the outcome while retaining the essence of the visionary ideas. These traits confirmed that this could be the concluding phase of the process, giving us candidates to advance into a new selection process.

### ***Encountered Challenges and Recommendations***

Regarding elements and methods chosen that turned out unhelpful or less suitable for the process, the focus on specific courses during ideation as well as the Pugh matrix as an evaluation method shall be discussed.

Mathematics is considered fundamental and characteristic of engineering programs. One of the visionary program proposals aimed to explore how mathematics courses could be designed in the program to be more motivating for students. The team was inspired by how this was done for a mechanical engineering program where the mathematics courses were reformed to support the parallel mechanics and strength of material courses (Enelund & Larsson, 2006). In our project, mathematics would instead support the design subject. Such a proposal was made in this project, but one of the lessons learned is that a multifaceted competent group is needed to work further with it.

The Pugh matrix that was used for evaluation produced a very useful result for the process, but not in the usual form of ranking the drafts. Due to the weighting of criteria, different perspectives, and addressing significant issues, the assessment was not so black and white that a "+" or "-" could be unequivocally assigned. Therefore, the most valuable result was the comments and reflections that emerged during the method's implementation, which were carried forward into the subsequent steps.

For future implementations of the Pugh matrix in the execution of this methodology, a very detailed definition of the criteria should be conducted before the method is carried out. Other alternatives could have been to choose another method to support a systematic discussion, or to conduct a weighted matrix, such as a Kesselring matrix.

Conducting user testing in the development of a program curriculum presents challenges due to its intricate nature concerning time and scope. This was no exception when employing the product development methodology in crafting the program plan. Nevertheless, a survey was conducted during the process, and responses from students offered valuable insights into their anticipated needs, preferences, and expectations, thereby enriching the scope of considerations.

## **Research Contributions**

Regarding the research questions outlined in the introduction, the project addresses them through the presented results and the generated final draft of a program curriculum. The outcome of this study gives a first answer to the question of how a product development process can be applied to program development. Due to the multi-faceted nature of this inquiry, the answer may not be comprehensive, yet it enhances our understanding of the subject in whole. These results can therefore serve as a reference for future investigations into potential enhancements to this methodology and approach. The output, which is the framework of the new design program, will undergo further refinement and evaluation to determine its suitability for the flexible program scenario that is aimed for.

## **CONCLUSION**

Utilizing a product development methodology to the creation of a new program curriculum proved successful and remained effective throughout the entire process. A particularly beneficial aspect, recommended for retention, involves introducing a method early in the process that broadens perspectives, allowing ideas to stay expansive for a significant period. Following this, the use of a defined method to narrow down ideas facilitates visionary solutions in the early stages without overlooking crucial aspects, as there is ample time for refinement in later phases. Another successful element was the inclusion of a forward-thinking trend scouting in the pre-studies, bringing diverse perspectives and proving vital for the project's foundation.

Drawing lessons from this project, suggested modifications for the next implementation primarily involve refining method selection to enhance results further. This includes ensuring precise and well-arranged criteria for the program, such as sufficient credits, included subjects, and alignment with university aims and values. This precision is essential for the chosen evaluation methods and plays a crucial role in refining the programs into more realizable drafts. Equally important is planning and defining the goals for each step throughout the entire upcoming process, providing all members with the necessary knowledge early on to execute the methods properly and achieve the desired outcomes.

In conclusion, the successful application of a product development methodology in creating a new program curriculum emphasizes the significance of early broadening perspectives, defined approaches for focused development, and maintaining a close connection to the initial aims and purpose.

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# **MASTERY LEARNING IN INTRODUCTORY PROGRAMMING: RUNNING A PROJECT ALONGSIDE A TEST LADDER**

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## **ABSTRACT**

Many students struggle to learn introductory programming, especially computing non-majors. Teaching designs where all students are expected to keep the same pace, will be too demanding for some students, who are left without any sense of mastery – and at the same time boring for other students who are quick learners or have previous knowledge of programming. Hence, self-pacing could be an interesting paradigm for programming courses. The current paper reports on the transition of the introductory programming course for first-year STEM teacher students at the NTNU, from a traditional lecture/exercise/exam design to a learning design inspired by mastery learning, with a series of automated tests in parallel with an individual programming project. The course design showed some positive and promising results in terms of a very low failure rate and good student satisfaction across a wide range of progress paces and ambition levels. At the same time, there were also some negative issues. While most students started early with the tests, many struggled to get started with the project, and the grade average was poor.

## **KEYWORDS**

Programming, Mastery-learning, Assessment, Project-based learning: 2, 5, 8, 11

## **INTRODUCTION**

Learning to program is challenging for many students (Bennedsen & Caspersen, 2019; Matthíasdóttir & Loftsson, 2020), and especially for computing non-majors (Wiedenbeck, 2005). The so-called learning edge momentum (Robins, 2010) implies that programming concepts build upon each other in such a way that students who fall behind the nominal progress of the class are likely to fall further behind rather than catch up. Hence, mastery-learning with self-pacing inspired by Keller's Personalized System of Instruction (Keller, 1968) might be an interesting intervention, and recent adaptations of mastery learning in introductory programming courses have reporting promising results despite some challenges with student procrastination (Ott, McCane, & Meek, 2021; Puroo, Sein, Nilsen, & Larsen, 2017).

In Norway, there are many 5-year master programs for students seeking to become teachers. NOKUT evaluated these programs and found a need for improvement, especially related to motivation and sense of belonging in these study programs. At the NTNU, one of these programs is for students wanting to become high school teachers in STEM subjects. A general initiative was started to improve this program. The most radical change was to design an introductory programming course specifically for this student group, rather than having them take the standard CS1 course together with many other STEM programs. Goals for the new programming course were: (1) improved sense of belonging, by giving the class one course specifically for them in the first semester, instead of just having huge auditorium lecture courses together with other programs. (2) increased professional relevance for teacher students, by looking at the usage of programming related to teaching of STEM courses in high school. (3) piloting a radically different course design, which could more easily be done in a small class of 50 students, than in one of the standard CS1 courses with 500+ students. Moreover, students who themselves are on a path to become teachers, could benefit from having been exposed to widely different course designs during their studies, rather than too many courses with a standard set-up of plenary lectures and end-of-course exams.

A central aspect of mastery learning is to have a series of tests, but such automated tests would typically focus on short code snippets and rather generic problems. Hence, it was considered necessary to have a programming project alongside this series of tests, so that the students could learn to write code. The project was also the component meant to ensure the increased relevance of the course, inspiring the students to design a program relevant for their major study discipline and future profession. The research questions we are investigating in this paper are as follows: (RQ1) How did the students perform in the course, and especially on the project running alongside an automated test series? (RQ2) How did the students experience the course in general, and the project in particular? For the first question, we look at log data showing the students' progress, as well as inspect their delivered code. For the second question, we look at students' perception as expressed through a questionnaire survey.

The rest of this article is structured as follows: Section 2 presents the design of the new course. Section 3 explains the research method for evaluating the course, whereupon findings are presented in section 4. Section 5 provides a discussion of the results, both compared to related work and providing ideas on how the course could be improved for the next offering. Finally, section 6 makes some concluding remarks.



## COURSE DESIGN

Inspired by mastery learning / Keller's PSI, the course was divided into modules. The content of modules is indicated in Table 1.

Table 1. Course modules

|   | Key concept(s)          | Also covered                                          |
|---|-------------------------|-------------------------------------------------------|
| I | Variables, assignment   | Names, arithmetic operators, precedence, input, print |
| H | Data types, functions   | Lists vs. numpy arrays, simple plotting in matplotlib |
| G | Conditions, branching   | f-strings                                             |
| F | Loops                   | Indexing in sequences, augmented assignment           |
| E | 2d data, double loops   | Simple usage of files                                 |
| D | Exception handling      | String methods, files, slicing                        |
| C | Sets, dictionaries      | More about list methods, mutability                   |
| B | Functions as parameters | Mitigating rounding errors                            |
| A | Recursion               | More difficult problems across the curriculum         |

Each student could then choose their own pace and ambition level through these modules. The lowest passing grade in the Norwegian system is E (similar to the ECTS system), which would correspond to a D in the American system, and the top grade is A (there are only the letters E, D, C, B, A – no A+ or A-). Hence, the modules directly corresponded to grades. To pass, a student would need to do the 5 first modules (I, H, G, F, E), and each grade upwards from that E would require mastery of yet another module. Mastery of a module had to be documented by passing a test (starting at module I) and a project (starting at module G).

**The tests** were fully automated, with one test per level I, H, ..., A. Each test typically consisted of 8-10 tasks, together covering the concepts of that module. Commonly used question genres were multiple choice, multiple true/false, pairing, Parsons' problems, and various code completion tasks (code with gaps to be filled). The pass threshold was initially given as 90%, and a failed test could be retaken the next week with no penalties. Summative tests for passing a module were conducted under supervision. In addition, there were practice tests for formative usage. Both types of tests drew question randomly from the same question banks, with approximately 20 variants per task, so that students would rarely get the same questions with repeated attempts – this to encourage understanding of the concepts rather than mere memorization of answers. With practice tests thus being identical to supervised tests (except for different outcomes of the random drawing) there was a high level of transparency to the tests, where practice tests could be used formally for gradual improvement before a supervised test. Seeing where they lost points on a practice test, students could then look at videos and notebooks explaining those concepts to improve their scores. Similarly, if failing a supervised test, students could look at the results and see where they needed to improve before reattempting the test the next week.

**The project** was done individually, with incremental deliveries through the semester – again open for different paces among students. Although team projects can have many affordances (Pee & Leong, 2005; Säisä, Määttä, & Roslöf, 2017), such as collaboration skills, students learning from their peers, we considered it too risky within a course design of self-pacing. There have been courses using team projects in mastery learning courses, such as (Jazayeri, 2015), but then the project was towards the end of the course, and only for students who had passed the previous mastery tests in nominal time, so the slower students would not be exposed to any project. Our individual project could more easily be done in parallel with the module tests and available for all students, regardless of pace and ambition level. Every student was free

to define the objectives of their project and what features the code would contain, within some broad requirements: (I) The program should be intended for pedagogical usage within the student's major discipline. Hence, a student aiming to become a biology teacher should make a program to be used in the teaching of some topic within high school biology, whereas another might do something within high school math, physics, or chemistry. (II) For each module, the code must demonstrate purposeful usage of the key concepts included in that module. Hence, to reach the grade of E, the project code had to include concepts covered in modules I through E, cf. Table 1. A student who then wanted to improve the project from E to D would need to add some code to demonstrate purposeful usage of exceptions, string methods, slicing, and file handling, cf. Table 1. (III) The program must run without error and give some understandable output to the user. With each delivery, the students attached a self-evaluation checklist indicating how requirements were met (e.g., in which code lines various concepts had been used). It was decided to start project deliveries at level G, since at levels I and H students might know too little programming to write coherent code. Also, this gave students time in the beginning of the semester to think about what type of project they would want to make.

As for **grading**, there was no percentage score for the tests and project, instead students climbed a pass/no-pass mastery ladder, and if test and project were at different levels at the end of the semester, the lowest grade would result. Hence, it would be pointless for a student (at least from a grading perspective) to achieve a high level on the project while staying at a low level on tests – or the other way around. It can be noted that a student satisfied with the lowest passing score would only learn the concepts covered in the first 5 rows of Table 1, thus for instance not learning about exception handling, sets, dictionaries. The rationale for this design was that it was considered better to ensure that all passing students had good mastery of a limited number of programming concepts, so that they could actually do something useful with them, rather than giving them superficial understanding of a broader range of concepts, which might have resulted if we had tried to cover all concepts in a basic way within modules I-E and then looking at more advanced usage in further modules.

**Teaching and learning resources.** There was no defined textbook for the course, but Jupyter Notebooks and videos had been made beforehand for the topics covered in each module, and some example projects had been developed, at grade levels E, C, and A. The practice tests were also a key learning resource. In addition, the course had weekly seminars (10-12 every Thursday), with compulsory attendance of at least 11 of 14 seminars. During seminars, students would sit together at group tables, typically organized according to level of progress and what type of learning activity the student wanted to pursue. For instance, students practicing for the E-test would sit at one table, F-test at another table, G-test yet another table, and students wanting to work on their projects during the seminar at yet other tables. Teaching staff (teacher and TAs) would help students along the way during seminars.

## RESEARCH METHOD

Student performance (RQ1) was evaluated by looking at grade statistics, plus aggregate observations about student progress on tests and project made by the teacher during the term. For privacy reasons we could not use more detailed log data from the LMS and digital exam system in the analysis. Students' perception and satisfaction with the course (RQ2) was investigated by a questionnaire survey. This survey was administered in the classroom in the beginning of the seminar in the 11<sup>th</sup> teaching week, and 44 of 48 students in the class responded, giving a response rate of more than 90% (non-responders being students who happened to be absent from that seminar). The survey was anonymous and thus in compliance

with requirements by SIKT (The Norwegian Agency for Shared Services in Research). This was achieved using the national questionnaire platform Nettskjema, which explicitly avoids capturing indirect electronic identifiers from the respondents. Since the questionnaire investigation was anonymous, it is not possible to correlate student grades with the questionnaire answers, and hence impossible to see, e.g., if satisfaction was correlated with achievement.

## RESULTS

### ***Findings on RQ1: Student performance in the course***

A positive result for student performance was the zero failure rate. Table 2 shows the grade distribution resulting from our course in 2023 compared to what the STEM teacher students of 2022 got. In 2022, with a more traditional course design, the failure rate was 11% for students who did attend the exam but scored too poorly. However, there were some other less satisfactory aspects of the performance. The grade average was only D, since more than half the class only achieved the lowest passing grade E. As shown in Table 2, less than half the class achieved better than E. Notably, the 2022 cohort of the same study program, who had a more traditional CS1 course, also had a grade average of D, but then at least on the positive side of D, so the 2023 average was 0.3 grades lower.

Table 2. Grade distributions %, 2022 (trad. exam) vs. 2023 (mastery learning)

| Grade | A          | B          | C           | D           | E           | F           |
|-------|------------|------------|-------------|-------------|-------------|-------------|
| 2022  | 5.6        | 2.8        | <b>30.6</b> | <b>33.3</b> | 16.7        | <b>11.1</b> |
| 2023  | <b>6.4</b> | <b>8.5</b> | 8.5         | 14.9        | <b>61.7</b> | 0           |

In the first 4-5 weeks of the semester, the average speed of the class up the test ladder would have yielded a grade average closer to C than D if it had persisted, which would have been an improvement over the year before. However, then the average pace slowed down. The F-test and E-test turned out to be notably more difficult than the previous tests, some students needing several attempts on these. Also, the project work lagged the test-taking. Especially in the first half of the semester, many students had a slow start to the project. However, students had a wide range of different paces – which the self-pacing course design was also intended to allow for.

As for the projects, students were free to choose what kind of program to make, only that it had to be related to their discipline. Already in the first semester, these students choose between 5 different specializations within the program: Math + Physics, Math + Chemistry, Math + Biology, Chemistry + Biology, and Math + Informatics. Each student was required to make a project related to their specialty subject(s) and its teaching in high school. Hence, every student would have two choices, for instance, a Math + Physics student could either make a program related to the teaching of math or to the teaching of physics. Chemistry and biology were the most popular topics, while few students chose math, even if most of the class could have done so since math is included in 5 of 6 study directions. Also, few chose physics, and nobody chose informatics. Regardless of discipline, the structure of the delivered code was mostly poor. One symptom of this is the limited use of functions, as most students had the bulk of their code in the main script. There was no absolute requirement to use a particular structure for the program, but students had been recommended to decompose their code by means of

functions, as the curriculum for the course was procedural programming in Python. Many students missed better teaching support on how to structure their code.

There was a wide range of exact curricular science topics covered by the programs, such as in biology: genetics, ecology, plant growth, epidemics; in chemistry: molecules, reactions, acids and bases; in physics: ballistics, free fall with air drag, bouncing and elastics; in math: equations, fractions, geometry. Also, there were some different genres of programs: calculation and visualization, data support for experiments or field trips (entering and analyzing data), simulation of natural phenomena, and quizzes. Even if they struggled, many students seemed to find it motivating to write a program with a pedagogical purpose related to their future profession.

### Findings on RQ2: Student experience with the course

Figure 3, upper left, shows how students responded to the question *How satisfied are you with this course?* on a 5-point scale from very dissatisfied to very satisfied. Only a small share of the students chose the negative options, and most responses were positive. Compared with other courses they took in parallel which had a more mainstream design with lectures and end-of-course exams (upper right), 64% felt this course was better, while only 16% felt it was worse. Lower right shows responses to the statement *I have experienced mastery in this course*, again with a majority for the positive options. One aspect that students were less satisfied with, was the teaching and learning resources related to the start of the project, which many found difficult (lower right), with a clear majority responding very challenging or challenging.

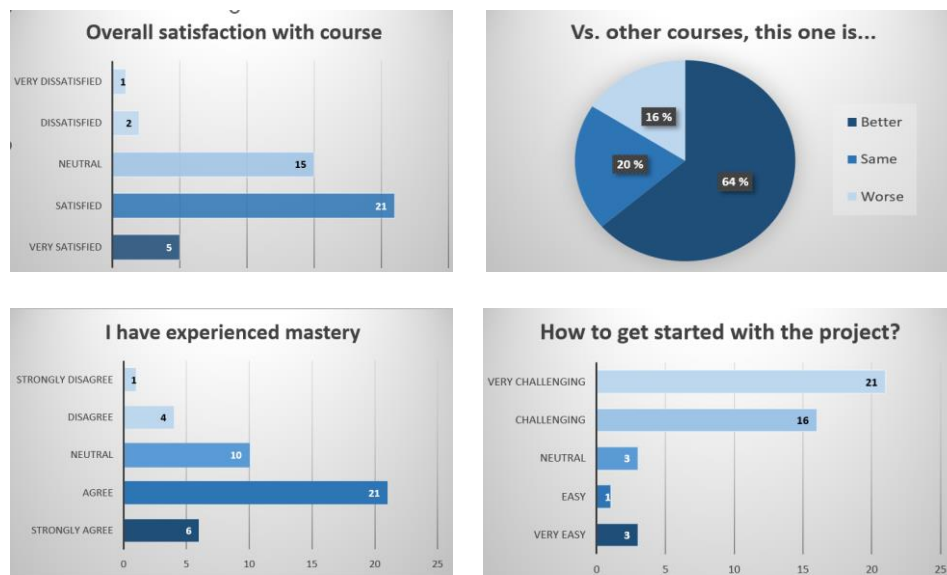


Figure 3. Course satisfaction as such (upper left) and vs. other courses (upper right), perception of mastery, and ease of starting project (all: dark = better, light = worse)

It can also be interesting to look at the students' opinions on the usefulness of various learning activities and resources. This is shown in Figure 4, with the columns left to right being very low to very high usefulness. The one thing that really stands out in this diagram is the very high perceived usefulness of the practice tests. No students have given negative answers about these, and a clear majority (37/44 respondents) have rated them as very useful. Other

resources also get good scores, except the demo projects, where there are more negatives than positives.

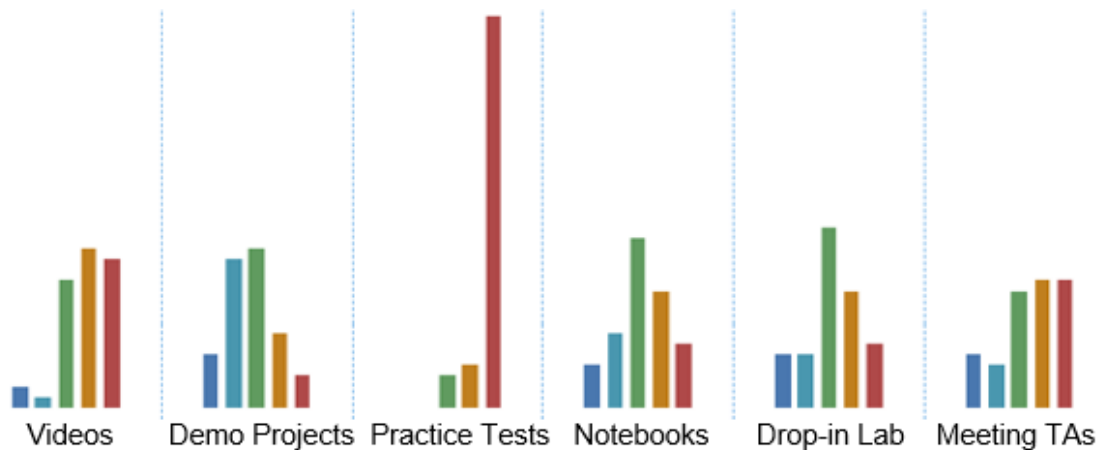


Figure 4. Perceived usefulness of six different learning resources in the course, each with responses from very low (left, dark blue) to very high (right, red)

Students were also asked several other questions in the questionnaire, but for space reasons we cannot present all the results here. One of the questions was about which learning resources they used in connection with the project work (multiple selections allowed), the results were tutors (82%), peers (73%), teacher videos (55%), demo projects (41%), practice tests (32%), and other (30%) – which might have been other internet coding resources such as StackOverflow or YouTube videos, or generative AI like ChatGPT. Since only 32% reported usage of practice tests in connection with the project, while these are the clear “winner” in the overall usefulness questions shown in Fig.4, it seems reasonable to assume that the practice tests were primarily considered useful for passing the supervised tests, and less (but not zero) for doing the project.

## DISCUSSION

### *Related work*

Mastery learning has been used in many universities and disciplines throughout the years. Key ideas for mastery learning emerged in the 1960’s, in particular Bloom’s *Learning for Mastery (LFM)* and Keller’s *Personalized System of Instruction (PSI)* (Bloom, 1968; Keller, 1968). One earlier example of a PSI-inspired approach to introductory programming is (Purao et al., 2016), which like our course allowed for a high degree of student self-pacing. Unlike our course, they did not decide grades solely based on the passing of modules but by an end-of-course exam, and they had several smaller programming exercises rather than an incremental project. Indeed, many applications of mastery-learning in introductory programming have been hybrid, combining a mastery ladder with a traditional end-of-course exam and some plenary lecturing (Garner, Denny, & Luxton-Reilly, 2019), and few have combined mastery learning with a project. An exception is the previously mentioned approach by (Jazayeri, 2015) including a team project, though differing from ours in that the project was only towards the end of the course, for those who had passed the other modules, hence the weaker students would not get any project. The course reported by the paper (Toti, Chen, & Gonzalez, 2023) had a course design resembling ours in that the passing of modules was directly linked to grades. They had

project as the very last of 12 course modules, which would thus only be taken by students going for the top grade.

### ***Interpretation of Findings***

For RQ1 about performance, the results were mixed. On the positive side, the failure rate was much smaller than previous years. On the negative side, there were fewer students achieving grades C and D, and instead more achieving E, so that the overall grade point average was weaker than the year before. Partly this may have been because some students decided to stop at E, thus having secured a passing grade in the programming course while they were more worried about some of the other courses they were taking in parallel. Some ended on E because that was the best they could manage within the time and capacity they had available, or because they believed it was the best they could manage, having struggled with the F and E tests and fearing that the D test was even more difficult. Others may have easily been able to take more tests, having passed the E test already by mid-semester – but had made less progress on the project, so then took a break from testing to work more on the project for a while.

For RQ2 about satisfaction, students seemed overall quite satisfied with the course, and most of them considered it better than other courses taken in parallel. However, this finding must be taken with some caution. The questionnaire survey was conducted in week 44, i.e., three weeks before the end of the teaching period. At this point, many students had already secured a passing grade in our course, while in other courses with a final exam, they obviously had not. Hence, some may have been more worried about, and less satisfied with, other courses for that reason. The very high level of satisfaction with the practice tests must also be taken with some caution. In a way, this is a self-fulfilling prophecy. Since the practice tests were identical to the supervised tests (drawing questions randomly from the same question banks) they will obviously have been perceived as highly relevant in preparing for the tests, which again linked directly to grades. The videos (second most popular learning resource) were also structured in a way that was closely aligned with test tasks. What can be derived from this is that students appreciated the high level of transparency inherent in this test ladder design. This transparency made it clear what you had to learn to obtain a certain grade, thus making it possible to take the lowest passing grade E in a controlled manner. With a final exam, on the other hand, some students who would be satisfied with an E will end up preparing to a higher level to have a margin of error at the exam.

Another positive take-away from the course is that even with self-pacing causing the class to be spread over several different grade levels already by mid-semester, and although projects were individual, students report collaborating a lot with their peers both in preparing for tests and in project-work. A key factor for facilitating this was probably the seminars with compulsory attendance, which helped students find other students who were at the same testing level (for collaborating about test preparation), or who, despite different project topics, had similar challenges with those projects (e.g., how to use a loop, read data from file, or plot a graph). Seminars also contributed to a sense of belonging in the class and study program.

## **CONCLUSIONS**

From the results, in particular the overall student satisfaction and low failure rate, a course design with a mastery ladder directly linked to grades, and with an incremental project in parallel with a series of pass/fail mastery tests, can be viable. However, this first pilot offering

of the course also had some issues which need to be improved. Some of the tests were too difficult when the pass requirement was 90%, in particular the F and E tests. The learning resources for the project were insufficient. The demo projects may have given the students good examples of what a finished project might look like, at levels E, C, and A. However, what they needed most help with was how to get from nothing to level G, and then onwards to F and E. Hence, before the next offering we will develop better learning resources and more scaffolding for the project, in the form of templates they might start with and adapt to various topics, rather than staring coding from an entirely blank editor window.

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# EXPLORING AI-DRIVEN PROGRAMMING EXERCISE GENERATION

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## ABSTRACT

Large language models (LLMs) are transforming how teachers work. In this paper, we observe several experimental approaches to generating software programming exercises by utilizing ChatGPT, a popular and open LLM. The generation of these exercises was tightly connected to a large Python programming course that was targeted at students studying in Information Technology, Software Engineering, and Computing.

We experimented with three separate approaches. In the first one, we generated new programming exercises with a specific topic using theme injection. In the second one, we generated variations of existing programming exercises by changing the theme or content. In the third one, we generated hybrid exercises by injecting original programming exercises with additional topics or other related exercises.

Based on our results, all three approaches showed potential but also revealed limitations. The exercise generation with theme injection can produce fully functional exercises. However, these exercises could appear to students as too generic or erroneous. The exercise variations seem to retain the semantic meaning of the original exercise quite well while still using different context. We also tested the variations in a large introductory programming course and found out that the students could not distinguish them from human-generated exercises in style or quality. The hybrid exercises were built upon the idea of exploring how close we are to fully adaptive learning environments in the field of programming education. The current results of this approach show that we need to do further experimentation to maybe reach the goal.

All in all, it was evident that LLMs can be a useful tool in assisting teachers in generating exercises. Even with certain coherent limitations, they are useful in particular cases. We conclude our article by discussing the future possibilities of LLMs, including but not limited to dynamic, automatically generated exercises and fully adaptive learning environments.

## KEYWORDS

AI in Education, LLM, Programming Education, Pedagogical Tools, ChatGPT, Standards: 2, 3, 5, 8, 9, 11

## INTRODUCTION

The field of generative AI has advanced rapidly in the recent years. These innovative AI tools are revolutionizing work processes across a wide range of industries by automating routine tasks. The field of teaching and education represents a prime example of an area where the potential of generative artificial intelligence has been a topic of conversation. In the study conducted by Nelson and Creagh (2023), it has been observed that the rapid development of generative AI tools has sparked numerous discussions and advice forums on how best to integrate them into both teaching methods and assessment practices.

ChatGPT is a Large Language Model(LLM), trained to answer a prompt given by the user and it is based on a similar architecture as InstructGPT (Ouyang et al., 2022). These models can perform well in different tasks, e.g. code generation and text summarization (Bubeck et al., 2023). These systems can now generate coding exercises and even multimodal models are being trained, E.g. Gemini by Google DeepMind. Team et al. (2023).

Teachers are often pressured for time. Teacher's workload can be further increased by large student groups, or tight schedules not to mention creating and updating study material for courses. ChatGPT and other new LLMs can help to reduce the time needed for content generation for courses. To reduce workload of the teachers and to explore the capabilities of these new models, we have explored the possibilities of how to utilize AI when creating programming exercises. The performance of these models also sparks a question of which parts of the programming education can be automated with these new AI tools.

The paper is structured as below. Section II describes related studies conducted by different researchers across the world and Section III explains the methodology that we used to conduct these experiments. Section IV describes a set of limitations that we observed during the exercise generation. Section V discusses the results and observations in detail and the Final Section concludes the findings of our study.

## RELATED WORK

Crawford, Cowling, and Allen (2023) suggests that educators can utilize AI tools such as ChatGPT to create supportive learning environments. The paper acknowledges existing literature on plagiarism and academic integrity and discusses the role of leadership in supporting the ethical use of AI. In Sovietov (2022), the authors focus on the automatic generation and grading of programming exercises. It describes the general scheme for constructing a programming exercises generator, highlighting two classes of exercises that can be automated: converting notation into code and converting data formats.

Another study conducted by Wang, Singh, and Su (n.d.) discusses the "Search, Align, and Repair" (SARFGEN) data-driven program repair framework for automating feedback generation in introductory programming exercises. The framework aims to provide efficient, fully automated, and problem-agnostic feedback for large-scale or MOOC-style courses by leveraging a large number of student submissions.

Speth, Meissner, and Becker (2023) has investigated the use of AI models, like ChatGPT, for creating exercises for programming courses. It involves creating exercise sheets with ChatGPT for a beginner to intermediate programming course and assessing the quality of these exercises in an actual course setting.

Despite all the capabilities of AI tools like ChatGPT, it should also be highlighted the possible risks that generative AI has introduced to the field of education. The study by Nelson and Creagh (2023) discusses valid concerns regarding the integrity of assessments and the potential reputational risks for educational institutions with the introduction of AI tools. It further encourages educators and researchers to explore how these tools can be used effectively and ethically to enhance learning outcomes and student capabilities.

## STUDY SETTING AND METHODS

Our approach was explorative. During our experimentation with AI-driven programming exercise generation, we decided to focus on three distinct approaches.

1. Generating exercises from a specific topic with theme injection,
2. Generating variations from existing exercises by changing the context of the original exercise, and
3. Generating hybrid exercises by injecting original exercise with additional topics or with other exercises.

All of these approaches have different use cases, strengths, and limitations. we have experimented with both models of ChatGPT (GPT-3.5 and GPT-4). As a more general note, we found that GPT-4 tended to create better, more "creative" exercises. The examples presented in this study are generated with GPT-4. We also note that the performance seemed to have improved since the original experimentation was done in the summer of 2023.

### ***Generating exercises from a specific topic with theme injection***

The first approach was to generate whole new exercises from a given topic and theme. The main drawback of this method seems to be that the exercises are often shallow and generic or lack the necessary supplementary materials. Still, the approach can be useful. An example of a prompt that is used can be seen in Table 1.

It seems to be possible to use almost any theme successfully, as we experimented for example with *the medieval times* or *working in an office* as themes. Due to the nature of LLMs, the quality of generated exercises can vary heavily. However, sometimes just re-generating the exercise with the same prompt provided sufficiently better results. Providing more context seemed to always improve the quality of generated exercises. One example of utilizing more descriptive context can be seen in Table 2.

Table 1 shows an example of generating exercise from a specific topic with theme injection. The most relevant part of the prompt is the last paragraph. In this particular example, the topics have also been generated by ChatGPT, the topic generation prompt can be seen [here](#). The full chat can be viewed [here](#).

Table 1. Example of generating exercise from a specific topic with theme injection.

| Type  | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Input | <p>File Handling: Reading from and writing to files is a useful skill for many practical applications. Exercises List:</p> <ul style="list-style-type: none"> <li>• Exercise 1: Write a program that reads a text file and counts the number of words.</li> <li>• Exercise 2: Create a log file writer that records timestamps and custom messages.</li> </ul> <p>Create exercise descriptions for the above exercises. Let the exercise descriptions revolve around the theme of working in a cafe.</p> |

Table 2. shows an example of generating a Javascript exercise for students in a given university course. The objective of the exercise is to providing students with an inefficient code which is then required to revamp to a more efficient code by following green programming practices. The full chat can be viewed [here](#).

Table 2. Example of generating a Javascript exercise for students in a given university course.

| Type  | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Input | <p>Assume you are a university teacher who is teaching Green Programming to students. You are required to come up with an exercise to utilize good green programming practices in coding. Let's create a bad code example in javascript where the code has not followed the 5 of the best practices mentioned in the given chapter text. The final code should not be complicated, that even a student with low coding competency could understand. Chapter content is given below for your referral.</p> <p>&lt;chapter content&gt;</p> |

### **Generating variations of existing exercises**

Generating variations from existing programming exercises seems to be a very promising approach in exercise generation, as in our experiments it has produced usable results consistently. This generation can be used in different settings, for example for generating exercise variations for exams, or to display a more abstract problem set. These exercises could also be used to quickly generate additional exercises, even for an ongoing course.

This is the prompt we used to generate variations:

- *"You are a university teacher teaching computer science. Below is an exercise. Create variations of the exercise description below. These variations will be used in the exam on introduction to programming course. The variations need to convey the same or almost same meaning but use different context. Answer in Finnish."*

We noticed that this approach tends to perform best when there is a lot of context tied to a certain theme that can be changed. If the exercise contained mechanical instructions only, the variation often just paraphrased the original exercise and did not change (or introduce) a

theme. In this kind of case, injecting a theme into the prompt often produced a better quality variant.

### *Can students identify the LLM-generated variants?*

To test the quality of variants, we swapped 3 exercises to AI-generated variants in a final week module in an introductory programming course. A small survey was included where the students were asked if they identified the AI-generated exercises. The generated exercises were in Finnish, and only a couple of very minor grammatical fixes were made manually to match the wording of other exercises (i.e. "Write a function" instead of "Implement a function"). A total of 378 students answered the survey. The distribution of the submitted answers can be seen in Figure 1.

Additionally, the students were asked to describe how they detected the AI-generated exercises. The common reasons listed by the students were differences in the exercise formatting, spelling, structure, or tone of the exercise. The common nominator in the correctly identified AI-generated exercises was the differences in the wording and style formatting of the exercise. Interestingly, spelling mistakes and different and missing style formatting were also emphasized as reasons identifying the exercise as AI-generated in the wrong answers submitted by students. As seen in the figure, the vast majority of students were unable to identify AI-generated exercises from original ones. This result could probably be increased further by making sure that the AI-generated exercises have similar formatting, structure, and wording as other exercises in the course.

### **Generating hybrid exercises**

Hybrid exercises are the best showcase for the limits of the current generation of LLMs. The definition of a hybrid exercise is that you would have two exercises, or one exercise and an additional topic that could be uniquely combined to create a new exercise. Ideally, this new exercise would use a different theme, and solving it would require the skills that the exercises used to create it utilized.

Our original prompt produced mostly poorly constructed results, as the exercise descriptions it generated were often a bit nonsensical or illogical. Quite often, instead of creating a new, fully unique exercise, the combined exercise was simply a listing of both exercise descriptions one after another with rather slight modifications. The original prompt can be seen below:

- *"You are university teacher teaching computer science and software engineering. You are creating exam for students of introduction to programming course. Below are two exercise description. Combine them in an unique way in a new context.*

*Exercise 1:*

*<exercise description>*

*Exercise 2:*

*<exercise description>*"

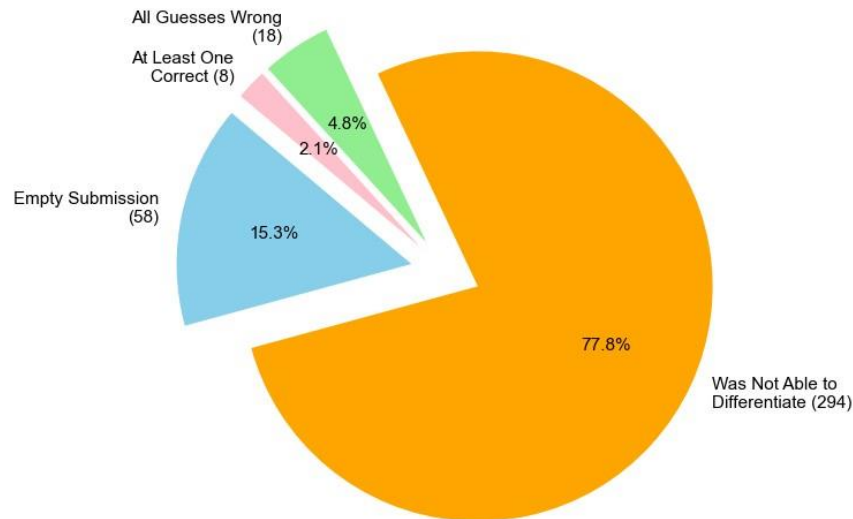


Figure 1. Answers to the survey about detecting AI-generated exercises (N=378).

No student could identify all three variations correctly. The actual amount is displayed inside parentheses. Half of those who identified at least one correctly tagged also exercises written by a human as AI-generated.

However, after we modified the prompt by utilizing a more well-defined and rigid structure, and made it utilize a chain-of-thoughts, the quality of the generated exercises seemed to increase significantly. A prompt used to generate a hybrid exercise can be seen below:

- *"You are a university teacher teaching computer science and software engineering. You are creating exams for students of introduction to programming course. Below are two exercise descriptions. Uniquely combine them in a new context. First choose a new theme for the exercise, then explain your rationale on how you will combine the exercises, and then finally offer the final answer of the combined exercise.  
Exercise 1:  
<exercise description>  
Exercise 2:  
<exercise description>"*

Still, we would like to note that our experimentations with hybrid exercise generation have still been fairly limited quantitatively and more research is needed for the topic.

### **Limitations**

The primary language used in ChatGPT's training data is English, which may affect its effectiveness in other languages Dave (2023). ChatGPT tends to generate convincing but inaccurate information, a phenomenon known as 'hallucination' Bubeck et al. (2023), and can also reinforce stereotypes. There are notable variations among different language models; for instance, GPT-4 generally surpasses GPT-3.5 across a broad spectrum of tasks OpenAI (2023). The proficiency of ChatGPT in executing tasks is also influenced by the subject matter and the clarity of the input prompt.

This is preliminary work, so more research is needed to find out the limitations of these approaches. Furthermore, quantifying the results we found with a more statistical approach could provide valuable insight into the limitations of these methods. We would like to also add, that utilizing more advanced prompting techniques could potentially improve the results further.

## DISCUSSION

The field of automatic programming exercise generation shows rapid advancements. However, the limits of methods discussed in this study are still a bit unclear. One should also remember that utilizing ChatGPT (or other LLMs) might have surprising caveats. For example, it might favor the first presented option when asked to compare multiple options (Dettmers, Pagnoni, Holtzman, and Zettlemoyer (2023)). Deng and Lin (2022) also point out in their study that ChatGPT may repeat biases or offensive language due to the data used in the model's training. Even with these potential fallbacks, the ease, speed and, surprisingly good quality of generated exercises show that LLMs can be valuable assets for a teacher.

In variation generation from existing exercises, we have not yet explored how well the models could fit the existing unit tests for exercises. They might perform quite well since the semantic information regarding new tests should be quite similar to the old exercise's tests. Another question is whether the models can do more complicated test modifications, e.g. when a datatype is changed from string to a number (for example when the exercise theme changes from the music to movie ratings) in the generated variation.

Even though in hybrid exercise generation the achieved results leave much to be desired, the foundation is still there. Defining a guideline for producing good programming exercises can be a difficult task since the guidelines will probably at least partly lean into values that can be seen as abstract, such as *creativity* or *innovativity* or *enjoyability*. Thus, we can argue that understanding the quality of a programming exercise can be a challenging task for a machine, at least for a while. It should also be noted that taking two arbitrary exercises and combining them can be a challenging and time-consuming task even for the most experienced teachers.

It should also be noted that ChatGPT is not deterministic. The answer given by ChatGPT in different threads can be the same, or paraphrased or it might even present an opposite result of a previously given answer in a different thread. When these approaches are directly used by the teacher, not by a student, the presented approaches do not need to work *every* time, but instead *most* of the time. Teacher can keep on generating new exercises until a suitable one comes along. Naturally, in an adaptive system where the exercises need to be generated on the fly, this is not possible.

## CONCLUSION

In this paper, we have explored the AI-driven programming exercise generation from multiple possible approaches. Although there are limitations, the chosen approaches show a lot of potential. Many of the generated exercises and exercise variants seem to be usable, especially after minor human-made modifications. It should be noted, that when the AI-generated exercise variants were used at the end of a large-scale programming course, the students who had already completed more than 150 human-made exercises, mostly could not distinguish between AI-generated variants and original exercises.

The different approaches presented in this study performed well. The theme injection's biggest challenge was to generate supplementary materials for the generated exercises. The exercise variation generation showed consistent results with high-quality output. The performance in hybrid exercise generation varied wildly depending on different factors, e.g. on the exercises used as input, but even the initial approach presented in this study could provide (sometimes) good results.

While we can say that fully adaptive learning systems are not here yet, approaches presented in this study can already be useful to teachers in a variety of different settings. Additionally, the applicability beyond the realm of computer science might be possible at least in some application areas, e.g. in generating math word problems. Furthermore, combining the techniques introduced in this study might create interesting results. More research, especially involving more advanced prompting techniques such as tree-of-thoughts is needed, and it is something we will probably address in a future paper.

As AI starts to play a bigger role in teaching methods, it's important for educators to stay alert. They need to make sure that the content AI creates is accurate and appropriate, and this responsibility falls on the person who creates the content to double-check for any mistakes or biases. The AI methods that we have experimented within this study look promising, but we need more research to understand their limits and the most prominent use cases. However, as the technology is rapidly developing, this may be challenging.

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# STUDENT PERCEPTIONS OF ETHICS AND USEFULNESS OF AI TOOLS FOR DESIGN ENGINEERING

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## ABSTRACT

AI tools have become increasingly popular and accessible in various domains, including industrial design engineering. However, there is a lack of empirical studies on how these tools affect the design process and outcomes, as well as the ethical implications of their use. In this paper, we present a research study that aims to explore how students at bachelor level in Industrial Design Engineering, particularly those without prior knowledge, perceive the usefulness of text-to-image generative tools. We also examine their main ethical considerations regarding the use of these types of tools, as well as AI tools in general. Our findings indicate a cautious but curious attitude towards AI technologies, underscoring the need for a nuanced approach in their integration into educational curricula. The apprehension towards adopting these tools reflects a broader concern about ethical implications, technological dependence, and the potential overshadowing of human creativity. However, the study also reveals an eagerness to understand and utilize these technologies, suggesting a latent potential for enhancing creative processes in design engineering. As our study shows, students are keenly aware of the challenges and opportunities presented by AI, highlighting the importance of clear guidelines and ethical frameworks. In conclusion, the integration of AI tools like text-to-image generative models in design engineering education presents both challenges and opportunities. The key to successfully navigating this integration lies in a balanced approach that emphasizes ethical usage, critical understanding, and creative collaboration. Through such an approach, we can prepare the next generation of designers to effectively and responsibly harness the potential of AI in their work, ensuring that human creativity remains at the forefront of design innovation.

## KEYWORDS

Text-to-image generative methods, Industrial design engineering, AI-tools in education, Ethic in AI, Standard: 6, 8

## INTRODUCTION

With the launch of Chat-GPT by OpenAI in November 2022, there has been a notable increase in the use and public awareness of AI tools. Chat-GPT is a Large Language Model (LLM) and a generalist tool that initially focused on understanding and producing text and code but has since expanded its capabilities to include image generation, among other functions. AI has long been a supportive tool in various sectors, but these new applications have significantly increased public awareness of its potential. In academia there have been several studies investigating the perception of use of AI in higher education, (Chan et al., 2023) and (Kumar & Raman, 2022). Concurrently, the rise of generalist AI tools has been accompanied by the emergence of specialist tools. These include Midjourney and DALL-E, which focus solely on image generation (text-to-image tools); GitHub Copilot, dedicated to coding assistance; and Elicit, which specializes in research overviews, to name just a few.

The introduction of AI tools has not been unequivocally positive, however. There are notable risks associated with these tools, both in terms of the quality of their output and the ethical implications of their use. These issues need thorough examination, and it is imperative to develop a deeper understanding and establish robust routines to address them at both a societal level and in everyday life. Given the staying power of these tools, it is crucial for the academic world to formulate a strategic approach, preparing students for the utilization of such tools before they embark on their professional careers. Accordingly, there should be clear guidelines governing the use of AI tools (see e.g., de Fine Licht, 2023).

To initiate this research and policymaking, it is important to explore how today's youth engage with these tools and their perceptions of the tools' usefulness.

Aim:

In this paper, we present results from a study aimed at investigating how students at bachelor level in Industrial Design Engineering, particularly those without prior knowledge, perceive the usefulness of text-to-image generative tools. We also examine their main ethical considerations regarding the use of these types of tools, as well as AI tools in general.

The research questions are:

1. What are the perceptions of text-to-image generative tools among students who are unfamiliar with these technologies?
2. What ethical considerations do students have regarding the use of text-to-image generative tools, specifically in professional and academic contexts?

## BACKGROUND AND THEORY

AI encompasses a broad spectrum of technologies and tools designed to simulate human capabilities through machine learning and complex algorithms. These tools can analyze vast amounts of data, identifying patterns, and make decisions or predictions based on the information they process. Among the diverse range of AI tools, some notable categories include large language models (LLM's) like OpenAI's GPT series, which are trained on extensive text corpora to understand and generate language in a manner reminiscent of human writing or conversation. Another significant category is text-to-image generative models, such as OpenAI's DALL-E and Midjourney, which can create detailed and coherent images from textual descriptions using advanced AI techniques. Building upon these advancements in AI, particularly in the realm of text-to-image generation, is the practice of

prompt engineering. This method involves crafting detailed and precise prompts or instructions to effectively guide generative models, enhancing the quality of the output by providing the model with clear and specific guidance. For example, a study by Liu and Chilton (2022) explores the impact of prompt keywords and model hyperparameters on producing coherent results and offers design guidelines for optimizing the performance of text-to-image generative models. These insights are crucial for harnessing the full potential of AI tools in creating high-quality, realistic images.

As these AI technologies continue to evolve and integrate into various sectors, their impact on educational environments has become a topic of significant interest and investigation. Through a year of workshops and discussions about AI tools in higher education with fellow examiners and teachers at the university level, as well as insights from the literature (see, for example, Neumann et al., 2023; Rudolph et al., 2023; Sullivan et al., 2023), we have made several preliminary observations.

Firstly, many teachers and examiners express concern that students might use these tools to cheat on exams. This fear has sparked a significant discussion about countermeasures, including the development of new tools designed to identify AI-generated text. Secondly, it is observed that students tend to adopt new technologies and hence these tools more quickly than teachers and examiners. This ties into the first point, highlighting a gap between what students can do with these tools and what educators believe they can do. Thirdly, and related to the first point, is the belief among many educators that these tools are easy to use, which implies that students don't need extensive knowledge to potentially use them for cheating. This appears somewhat contradictory to the second point, but not entirely, as many teachers and examiners do not use these tools themselves. Therefore, 'knowing how to use the tools' might simply mean understanding what the tools are and how to navigate them effectively. Fourthly and finally, many teachers and examiners believe that students are mostly positive towards these tools and are eager to use them and that the anxiety they may feel primarily stems from not having clear guidelines on what is permissible in their usage. Thus, one perception among teachers and examiners is that we don't need to incentivize students to utilize these tools, rather the opposite, we need to make sure against overreliance.

The use of Text-to-image generative tools is part of the CDIO Standard 8: Active Learning and 6: Engineering learning workspaces. Based upon the latest version of the CDIO standard (Malmqvist et al., 2020). Both as part of the digital learning workspaces as well as part of the active learning. The students explore the possibilities with the tools what it can do and what are the borders. The workshop and reflections are also connected to how words and taxonomy regarding design and expressions are intercorrelated to form.

## **METHOD**

To achieve user data different kinds of methods can be used such as interviews, questionnaires, surveys, focus groups etc. As a researcher you need to choose the right method depending on which type of research question you aim to answer, (Kvale, 1996). The retrieved user data also needs to be analyzed in either a quantitative or qualitative way. The quantitative data is numerical and can build up for example statistics and the qualitative data is focused in interpreting the answers and form knowledge on that material.

To give a preliminary answer to our research questions we utilized a workshop methodology. Workshop methodology is a participatory approach often employed in academic and professional settings to engage participants in hands-on, interactive learning experiences. This method involves organizing focused sessions where a small group of participants, typically with varying levels of expertise and experience, collaborate on specific topics or projects. Workshops are designed to be immersive and experiential, encouraging active participation, discussion, and knowledge sharing. The goal was to facilitate a deeper understanding of the subject matter, foster creativity, and stimulate innovative thinking. In educational contexts, such as in university programs, workshops can be particularly effective for introducing new technologies or concepts, allowing students to directly engage with the material and apply theoretical knowledge in practical scenarios. By combining instruction, collaborative exercises, and reflective activities, workshops offer a dynamic and interactive environment conducive to learning and exploration.

The workshop involved two groups of 35-40 students each, in the first and second year of the industrial design engineering program at Chalmers University of Technology. The idea with the workshop was to introduce AI tools with emphasis on Text-to-image generative AI tools, such as DALL-E and Midjourney to the students early in their education, to let them see the possibilities, limitations, and challenges of the tools, as well as to get an idea of what entry-level approaches the students have to these tools. We found that the knowledge and use of language models such as Chat-GPT was about 50% among the students, but the usage rate of Text-to-image generative tools such as DALL-E and Midjourney was significantly lower, around 20%. We introduced the basics of prompt engineering during the workshop, with a focus on text-to-image generative programs that differ from prompt engineering within language models.

In the workshop the students were allowed to try out the text-to-image generative tools and reflect on their usefulness, creativity, and ethics in terms of professional and academic contexts. We collected data from the workshop through observations and an open-ended reflective questionnaire that the participants should answer at the end of the workshop individually or in small groups. The questions posted was:

- How did you experience using this type of tool? Problems/Opportunities
- How did the use of AI tools affect your creative process during the workshop?
- How do you view collaboration between humans and AI technology in creation processes? What benefits or challenges do you see with this collaboration?
- Which ethical aspects related to the use of AI do you consider to be most relevant or important? Why?

The answers were then compiled and analyzed in a qualitative way to try to find preliminary answers to the posted research questions.

## **RESULT AND ANALYSIS**

The analysis was conducted qualitatively, and the results from this analysis are presented below in relation to each question posed. Additionally, results from observations made during the actual workshop are also included. The structure of the results and analysis chapter is as follows: each of the questions posed to the students at the end of the workshop is presented, and the answers are compiled into one to three main areas that were common in the responses. These areas are then further elaborated upon.

### ***How did you experience using this type of tool? Problems/Opportunities***

For most of the students, it was their first time using these kinds of tools, a factor that should be taken into consideration when interpreting the analysis results. In this section, three primary areas were identified, which are presented and analyzed below.

#### *Quick Inspiration and Visualization*

One of the things the students perceived was that the Text-to-image generative models were inspiring and fun to use but they also were frustrated since they did not achieve what they intentionally were aiming to create. Beginning with inspiration and visualization, a consistent theme was the appreciation of AI tools for providing quick inspiration and aiding in visualizing complex concepts. Students acknowledged that these tools facilitate idea generation and can make the creative process more efficient. However, there was a shared sentiment of frustration due to the tools' inability to perfectly capture their intended creations, highlighting a gap between expectation and output.

*"I found it a bit difficult to really achieve the intended images through text, you really have to practice how to phrase yourself to get a good result."* Student in second year

#### *Specification and Detail Challenges*

The students also faced challenges in effectively communicating their creative visions to the AI, often requiring multiple iterations to achieve desired results. This points to a need for more intuitive interfaces and improved AI understanding of human directives.

*"One advantage is that you quickly get a very detailed illustration. One challenge will be to communicate one's ideas in the right way."*

#### *Risk of Limited Creativity*

Interestingly, while AI tools were seen as enhancing creativity in some respects, there was a concern about the potential limitation of human creativity, suggesting a delicate balance in the integration of AI in creative endeavors.

### ***How did the use of AI tools affect your creative process during the workshop?***

In addition to the observations already mentioned, the questionnaire responses also revealed discussions about the practical use and technical challenges associated with AI tools. In this section three different main areas were identified, presented, and analyzed, below.

#### *Limitations and opportunities for creativity*

AI tools can sometimes limit creativity because they are based on existing data and have difficulty generating entirely new concepts. However, they can also enhance creativity by quickly generating detailed illustrations and providing new attributes and variations on existing things.

### *Challenges of Communication*

Students highlighted the iterative nature of working with AI, emphasizing both the potential for rapid prototyping and the challenges in achieving precise outcomes. This aspect underscores the evolving relationship between human intention and AI interpretation, where students often found themselves adapting their creative strategies to align with the capabilities and limitations of the AI. The need for multiple iterations to refine results highlighted a learning curve in effectively communicating with AI systems, pointing towards a potential area for future development in AI tools' user interfaces and interaction design.

### *Use as a Complementary Tool*

The students thought that the use of AI tools can help them develop their thinking and see how different words and sentences generate different results. This can make experimenting with different ideas fun and engaging in the creative process. AI was seen as a useful complementary tool, if they understand and know what is created in AI. It was perceived to shorten and expand the creation process and results. However, they express concern about becoming too reliant on AI. This would lead to a degeneration of knowledge and competence in the area.

*“As long as you understand and know what is created in AI, it can be a very useful complementary tool. On the other hand, it is not very good if you become dependent on AI and cannot create yourself if needed.”* Student in second year

### ***How do you view collaboration between humans and AI technology in creation processes? What benefits or challenges do you see with this collaboration?***

There will most probably be an interplay and collaboration between humans and AI in the future. Therefore, this was investigated. In this section three different main areas were identified, is presented, and analyzed, below.

### *AI as a Partner rather than a tool*

Moreover, the students' experiences brought to light the idea of AI as a partner in the creative process, rather than just a tool. This partnership, while offering novel avenues for exploration, also raised questions about the balance of creative control and the extent to which AI can or should influence the final output. These insights align with broader discussions in AI and creativity, where the intersection of human and artificial creativity is constantly being renegotiated.

*“I believe that collaboration between humans and AI is something that cannot be avoided but something that we need to learn to use to our advantage. In the creative process, I believe that we need to be vigilant not to give the entire idea generation to AI and not to start valuing the human creativity and creation process as something inferior to the AI's creativity and creation. So, it's about how we include AI in the creation process.”* Student in second grade

## *The Role of Humans*

Both groups emphasize the importance of humans maintaining control over the creative process. They see the human being as the one who comes up with well-thought-out ideas and who can decide what is better and worse. They also see humans as the ones who need to put their own stamp on things and not let AI mimic other people's work too much.

*"Humans need to have ideas and some kind of vision to feed the AI with information, which it can then work along. The human is the one who steers while the AI is the car that goes where we want to go. So far..." Student in first year.*

## *Ethical Considerations*

Regarding ethical implications, students were aware of AI's significant impact on employment, well-being, and the broader societal context. This encompasses concerns about AI replacing human roles, potentially leading to unemployment and a devaluation of human creativity.

### ***Which ethical aspects related to the use of AI do you consider to be most relevant or important? Why?***

The ethical aspect is of special interest and therefore scrutinized below. From the analysis of the gathered data, the students discussed the ethical implications of using AI tools to create images, by answering the question: What ethical aspects related to the use of AI do you consider to be the most relevant or important? Why? In the subsequent analyses, we identified different areas that the students found to be of main interest. Three examples of these were:

1. AI has a great impact on people's work, employment, and well-being,
2. AI has a great responsibility and power over people and other beings,
3. AI poses a great opportunity and a great challenge for people and other beings.

## *Ownership and Intellectual Property*

Another major concern revolved around the ownership of AI-generated content. Students questioned the extent to which creations made with AI assistance can be considered original and who holds the rights to such works. This ambiguity in intellectual property rights of AI-assisted creations poses a significant ethical and legal challenge. Lastly, the discussion also veered into AI's expanding role and its profound implications on human life and decision-making. Concerns were raised about AI making choices that could be deemed unethical in scenarios where it replaces human decision-making.

## *AI and Ethics*

Despite recognizing the challenges, students also saw AI as a valuable resource in reducing repetitive tasks and contributing to creative processes. This underscores the importance of a balanced approach where AI is used responsibly and ethically, complementing rather than supplanting human creativity and decision-making.

## *AI as a Resource*

Despite the concerns, there is also an understanding that AI can be a valuable resource that can contribute to creativity and reduce unnecessary and repetitive tasks. This underlines the importance of using AI responsibly and ethically.



At the workshop's end, students showcased their created images and reflected on the results and their creative process. There the students discovered that the AI interpreted their words differently than they had anticipated. For instance, using the term 'innovative' did not lead to the tool generating novel ideas, but rather produced futuristic representations of existing technical solutions. Similarly, the words 'environment' or 'environmental' prompted the AI to create images predominantly featuring green hues and elements like leaves or trees. They also encountered difficulties in incorporating text and creating human figures with accurate anthropometry in their images.

## **DISUSSION**

The workshop highlighted a somewhat surprising duality in the students' experiences with text-to-image generative models. On one hand, these AI tools were perceived as inspiring and enjoyable, playing a significant role in sparking creativity and aiding in the visualization of complex concepts. Students appreciated the efficiency and immediacy with which these tools facilitated idea generation, marking a notable advancement in the creative process. AI tools present an opportunity for students and practitioners to visualize concepts without extensive training in traditional sketching techniques.

However, this positive reception was tempered by frustration. Despite the initial excitement, students frequently encountered a disconnect between their creative intentions and the AI's interpretations. The tools, while adept at providing a starting point for creativity, often fell short in accurately materializing the students' envisioned outcomes. This discrepancy showcases the limits of AI in understanding and executing complex human creative visions and points to the necessity for further advancements in AI technology to bridge this gap. Thus, it might not be as easy to use the tools for the more advanced assignments you get at the university level and even if teachers and examiners are even worse at using the tools, this might suggest that the knowledge in how to use the tools in some aspects are still too low for the students to have that much of an upper hand with regards to the teachers.

Additionally, these albeit limited results suggest that students need to learn more about how to use these tools effectively, for example, by becoming better at prompting. This is easier said than done, as the teachers today often do not know how to do this properly and have limited time to learn. Furthermore, the models are continually tweaked and adjusted, and many more new tools are likely to emerge in the coming years. This presents a real challenge for teachers in enabling students to become proficient with these tools, particularly on the technical side. University professors also have many other responsibilities to manage. In many countries, they are facing an increasing number of students with the same resources. Consequently, if the AI tools do not become much more user-friendly, students might be left to navigate them largely on their own.

On a positive note, there are aspects teachers and examiners can impart to students that aren't as susceptible to change as those discussed in the previous paragraph. Firstly, we can teach them to express themselves and become knowledgeable about how to describe materials, moods, etc. This skill will likely always be essential in crafting effective prompts. So, even though many aspects of prompting may evolve, the ability to describe one's vision accurately and precisely might remain constant. This is already a focus in design programs, but there's potential for further improvement. Secondly, the norms governing the use of these tools and how their usage should be documented in academic writing have developed significantly over the past year. These norms are likely to become quite universal and, at least on a higher level,

stable. For instance, in a thesis, it will probably become standard practice to detail which AI tools were used, how they were employed, and their impact on the study. This is something we as teachers and examiners can help students understand and internalize. Thirdly, the integration of these tools into the workflow may also be less subject to change than previously thought. For example, treating AI not merely as tools but more as collaborators could be one approach. Determining how and when to utilize these tools to maximize creativity and avoid overreliance could be another.

Another more general finding from this study was that these groups of students expressed significant skepticism and anxiety towards these tools, which cannot be simply attributed to a lack of understanding about permissible uses within the university context. For instance, only about 50% of the students had tried out general-purpose tools like ChatGPT, and a mere 20% had engaged with text-to-image tools. This was somewhat unexpected, given that they are enrolled in a design program at a technical university where one would presume a greater inclination to experiment with tools aimed at assisting their core interest: designing. The students also voiced concerns about ethical issues related to these tools and the possibility of being replaced by them in the future. As one student aptly observed, we may need to view AI not just as tools, but as partners. However, it's also crucial to recognize the importance of human creativity and expression. Thus, in our study groups, there was a hesitancy to use these tools that seemed contrary to what one might expect. Instead of over-relying on them and neglecting key aspects of their program, they avoided using them altogether. This avoidance might be detrimental to their future prospects since these tools are not always straightforward to use, and they will likely need this knowledge post-graduation.

Thus, the need to adapt our curriculum to integrate these AI tools effectively becomes apparent. This adaptation should not only focus on the technical aspects of using AI but also on fostering a deeper understanding of its role and implications in the broader context of design and creativity. However, addressing these challenges extends beyond the realm of academia and requires action at a societal level. Legislative frameworks need to be developed to regulate the use of AI tools, ensuring ethical standards and responsible usage. These laws should aim to strike a balance between encouraging innovation and protecting the interests of those in creative industries. By doing so, we can provide students with compelling reasons to engage with AI tools, not just to enhance their immediate academic projects, but as a vital component of their long-term professional and ethical development. Ensuring that students are well-versed in these aspects will equip them to navigate the evolving landscape of technology and design, thus preparing them for a future where AI is an integral part of the creative process.

## **CONCLUSION**

In this study, we have explored the perceptions and ethical considerations of industrial design engineering students regarding text-to-image generative tools. Our findings indicate a cautious but curious attitude towards these AI technologies, underscoring the need for a nuanced approach in their integration into educational curricula. The apprehension towards adopting these tools reflects a broader concern about ethical implications, technological dependence, and the potential overshadowing of human creativity. However, the study also reveals an eagerness to understand and utilize these technologies, suggesting a latent potential for enhancing creative processes in design engineering.

We recommend that educators and policymakers take a proactive role in guiding students through the landscape of AI tools. This involves not only teaching the technical aspects of AI applications but also fostering a critical understanding of their ethical implications and practical uses in design. The incorporation of AI tools into educational settings should be balanced, ensuring that students are equipped to use these tools effectively and ethically. As our study shows, students are keenly aware of the challenges and opportunities presented by AI, highlighting the importance of clear guidelines and ethical frameworks. Moreover, the results emphasize the need for ongoing dialogue between students, educators, and the industry about the evolving role of AI in design engineering. This dialogue should address concerns about the potential replacement of human skills and creativity, while also exploring the benefits of AI as a complementary tool in the creative process. By embracing a collaborative approach, we can ensure that future designers are not only technologically proficient but also ethically informed and creatively empowered.

In conclusion, the integration of AI tools like text-to-image generative models in design engineering education presents both challenges and opportunities. The key to successfully navigating this integration lies in a balanced approach that emphasizes ethical usage, critical understanding, and creative collaboration. Through such an approach, we can prepare the next generation of designers to harness the potential of AI effectively and responsibly in their work, ensuring that human creativity remains at the forefront of design innovation.

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