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21ST INTERNATIONAL CDIO CONFERENCE

Proceedings – Full papers

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EDITORIAL

The 21st CDIO International Conference took place in Melbourne, Australia, from June 2-5, 2025, hosted by Monash University's Faculty of Engineering.

Our conference theme, "Forging Connections: Synergies for a Sustainable Future", reflected both aspiration and reality. Throughout the week, meaningful collaborations emerged across institutions, disciplines, and career stages. The genuine exchange of ideas, including challenges to established thinking, demonstrated the intellectual vitality of this community.

The conference program was deliberately designed to foster dialogue. Professor James Travelyan's keynote challenged us to examine CDIO's intellectual foundations and better capture what engineers do in practice. Madeleine McManus brought decades of industry experience to conversations about bridging the gap between educational outcomes and industry needs. Our student panel - Odette Maher, Selina Porritt, David Loven, and Ratu Esther-Kelvin - provided valuable perspectives on their educational experiences, reminding us that students are essential partners in educational innovation, not merely its recipients.

The CDIO Academy exemplified the framework in action. Students from Monash and Singapore collaborated on carbon capture module designs, working from our Design and Build Studios and presenting to international delegates. This hands-on, collaborative approach to learning remains central to CDIO's values.

This year's conference drew participants from 48 educational institutions across 28 countries, spanning all 6 continents, with 110 registered participants. The peer review process maintained high scholarly standards, with 81 members of the international CDIO community filing around 200 review reports.

These proceedings contain 50 Full Papers: 4 in the Advances in CDIO track, 32 in CDIO Implementation, and 14 in Engineering Education Research. These papers represent work by authors from 28 countries, representing 48 Institutions. Additionally, 3 CDIO Project in Progress contributions were presented (not part of these Proceedings), alongside 15 collaborative sessions across 6 Workshops, 6 Roundtable Discussions, and 3 Working Groups.

Several themes emerged across the conference. The roundtable on "Using CDIO for Non-Engineering Programs" explored how the framework adapts to architecture, built environment, and other disciplines, raising important questions about the framework's boundaries and applicability. Sustainability appeared not as an isolated topic but woven throughout discussions of curriculum design and implementation. Questions about evidence, rigor, and the relationship between CDIO practice and research emerged repeatedly, a healthy sign of a maturing field.

The facilities tours of Monash's Makerspace Network and Innovation Labs generated substantial discussion about the role of physical space in supporting experiential learning. Many participants left with concrete ideas for their own institutional contexts.

I acknowledge the substantial contributions of the conference organising committee - Tony Vo, Callum Kimpton, Colin Caprani, Joanne Tanner, Michael Crocco, Alexander Gregg, Andrew Rodda, and Julie Jerbic (Watermarks Events) - whose work made this conference possible. Professor Yiannis Ventikos, Dean of Monash Engineering, provided essential support,

recognising that hosting international discourse on engineering education aligns with our Faculty's mission.

The CDIO community continues to address fundamental questions about engineering education: How do we maintain rigorous evidence for our approaches? How do we prepare students for rapidly evolving professional contexts? What does genuine collaboration look like in educational settings? How do we integrate sustainability as a foundational rather than supplementary concern? These questions recurred throughout the conference, reflecting the community's commitment to continuous improvement.

The conversations that began in Melbourne continue through research collaborations, curriculum redesigns, and shared projects across institutions. Students who participated in the CDIO Academy have returned to their home institutions with new perspectives. Papers in these proceedings are already informing practice globally.

These proceedings are indexed in SCOPUS and represent rigorous scholarship on engineering education practice. They contain both successes and candid accounts of challenges, established findings and preliminary investigations, answers and unresolved questions.

To everyone who contributed to CDIO 2025 - through papers, reviews, presentations, facilitation, or thoughtful participation - thank you. Your engagement made this conference valuable.

The 22nd CDIO International Conference will be hosted by the University of Liverpool in 2026. I look forward to seeing how the community continues to evolve.

I hope these proceedings support your research, curriculum development, and teaching practice, and that they remind you of your place in a genuinely international community working toward excellence in engineering education.

Professor Nicoleta Maynard
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Associate Dean (Equity, Diversity and Inclusion)
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Melbourne, Australia, June 2, 2025.

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Advances in CDIO

Proceedings of the 21st International CDIO Conference, hosted by Monash University, Melbourne, Australia, June 2-5, 2025.

USING CDIO FOR DEVELOPMENT OF STUDENTS' SUSTAINABILITY MINDSET

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ABSTRACT

This paper uses the CDIO Framework to reconcile 2 separate areas of development work related to sustainable development: what constitute a set of key competencies for sustainability, and a set of sustainability mindset principles. To achieve the desired outcomes from education for sustainable development, that is, transformative learning, sustainability mindset is needed to drive actions, which requires a set of key competencies for sustainability. Our work argued that both are underpinned by the same set of skills and attitudes espoused in the CDIO Syllabus. Using the CDIO Standards, we also reconciled the apparent contradiction between "key competencies" which are meant to be context-independent (as in the work from the CDIO Community), and other authors who suggested "key competencies" which are clearly context-dependent. We suggested the use of a revised terminology that better reflect the current discourse and also the issues of order of hierarchy for the key competencies for sustainability. Notably, we improved on the work from the CDIO community and proposed a "bounded" model with values thinking competency as a "lower limit" and integrated problem-solving competency as the "upper limit". Values thinking competencies should be developed first based on underpinning skills and attitudes from the CDIO Syllabus. Our model allows other context-specific competencies to be incorporated as needed; and provides the flexibility of a program to formulate its own progressive pathway on how the rest of the key competencies for sustainability can be developed consistent with the program's own unique requirements. We also provide an application on how the model can be used for a hypothetical program. Lastly, we outlined some limitations in our work and how we can move forward in continuing to address this ever-evolving challenge.

KEYWORDS

Sustainable Development, Sustainability Mindset, Key Competencies for Sustainability, CDIO Syllabus, CDIO Standards: 1-12

INTRODUCTION

This paper outlines the work done to develop a general approach for any program in general, and Singapore Polytechnic (SP) in particular, that are interested in integrating key competencies for sustainability into a curriculum, guided by the CDIO Framework. This effort is an extension of the work done by the Diploma in Chemical Engineering (DCHE) after it introduced its integrated curriculum for sustainable development using the SP Common Core Curriculum (CCC). For more information, see Cheah et al (2022) and Oh et al (2023).

The work involves a pilot run involving 4 programs from 4 different schools in SP: School of Architecture and Built Environment, Chemical and Life Sciences, Electrical and Electronic Engineering, and Mechanical and Aeronautical Engineering. All programs had completed the integration of sustainable development into the respective curriculum, using selected United Nations Sustainable Development Goals (UNSDGs). Each program will build on the coverage of CCC to include disciplinary context to further enhance the coverage of sustainable development in each program. The goal is to develop a sustainability mindset among SP graduates.

This work brings together 2 different and separate strands of efforts related to sustainability: that of key competencies for sustainability and sustainable mindset principles, in order to equip SP graduates with sustainability mindset. The aim is to operationalize Education for Sustainable Development (ESD) to achieve the aim of transformative learning: students as "agents of change" (de Kraker et al, 2007), equipped with the capacity to go beyond just acquiring knowledge, but to use what they learnt to shape the future by proactively taking actions to address society's sustainability challenges. We believe the work shared in this work be of interest to other CDIO collaborators seeking to introduce ESD into their respective programs; as it provides a unified approach based on the CDIO Framework.

KEY COMPETENCIES FOR SUSTAINABLE DEVELOPMENT

The United Nations Educational Scientific and Cultural Organization (UNESCO) Publication Education for Sustainable Development Goals: Learning Objectives noted that key competencies represent cross-cutting competencies that are necessary for all learners of all ages worldwide, as they developed at different age-appropriate levels. They can be understood as transversal, multifunctional and context-independent (UNESCO, 2017). In the context of ESD, key competencies in sustainability are competencies that are relevant to all SDGs and enable individuals to relate the different SDGs to each other; representing what sustainability citizens need to deal with in today's complex challenges.

Within the ESD literature, various authors had suggested what constituted sustainability competencies or key sustainability competencies, e.g. Barth et al (2007), Frisk & Larson (2011), Kioupi & Voulvoulis (2019), Lozano et al (2017), Redman & Wiek (2021), Rieckmann (2012) and Wiek et al (2011). Many of these approaches had significant overlaps but despite this apparent convergence, there is no explicit consensus of a specific framework of key competencies in sustainability (Brundiers et al, 2021). Sterling et al (2017) described the situation as characterised by a sea of labels, terminological confusion, and relative inattention to pedagogic implications. Weinert (2001) is especially critical when he noted that: "The attempt to compile a comprehensive scheme above all possible and necessary key competencies is bound to fail right from the start since such a list must end in arbitrariness". Guia (2020) attributed this to the lack of universal competence framework for sustainability,

with the resulting proliferation of many definitions of what knowledge, skills, attitudes and values for sustainability are.

The starting point of our work is the same 8 UNESCO key competencies for sustainability, used by Rosen et al (2019) to evaluate the relevance of the CDIO Syllabus (then version 2.0) for promoting ESD in engineering. In the study, Rosen et al (2019) concluded that that the integrated problem-solving key competency in the UNESCO framework and aligned very well with the overarching Conceive-Design-Implement-Operate competences in the CDIO Framework. The 8 UNESCO key competencies for sustainability – systems thinking competency, anticipatory competency, normative competency, strategic competency, critical thinking competency, collaboration competency, self-awareness competency, and Integrated problem-solving competency – are formulated after extensive studies from other literatures noted earlier (Rosen et al, 2019).

In terms on terminology, which itself can be a source of confusion, anticipatory, normative and collaborative competencies as used above are the same as futures thinking, values thinking and interpersonal competencies suggested by Wiek et al (2015). Another reason why we choose the UNESCO publication is because it provided examples of cognitive, socio-emotional and behavioural learning objectives for each UN SDG; along with suggested topics for discussion and learning approaches. Another publication that provides examples for learning outcomes for key competencies for sustainability is from QAA-AdvanceHE (2021). This helped to address a challenge highlighted by Kioupi & Voulvoulis (2019) on the challenges of relating the SDGs to educational learning outcomes,

What the UNESCO document did not provide is the proficiency levels. To this end, we turn to the work of Wiek et al (2015) who introduced 3 levels of “mastery” to help operationalize the key competencies for sustainability: novice, intermediate and advance; which in turn can be translated to high school, undergraduate and graduate levels of sustainability education. This approach is consistent with the CDIO Framework; to aid the design of ESD via of an integrated curriculum to help progressively develop these key competencies for sustainability to the desired proficiency levels (learning outcomes); using appropriate UNSDGs as the learning context. In the case of SP, this translates to different competency level of our students’ sustainability mindset, as part of SP graduate attributes.

Hierarchy of Key Competencies for Sustainability

Several authors had spoken of “convergence” of key competencies for sustainability, for example, Brundiers et al (2021), Redman & Wiek (2021). These authors also spoken of the interdependencies of key competencies as each contributed to the overall integrated problem-solving competency. This is a positive development, moving away from what Wiek et al (2011) called “laundry lists” of competencies rather than conceptually embedded set of interlinked competencies.

However, even with the emerging “convergence”, there is still a lack of consensus among authors what constitute key competencies. These authors (Redman & Wiek, 2021, Brundiers et al 2021) readily acknowledged these unresolved debates and differing perspectives in their reported work. Brundiers et al (2021) for example suggested a need for a hierarchy of competencies; and improved on the initial framework of Wiek et al (2011) by introducing 2 new key competencies: intrapersonal competency and implementation competency. Like Wiek et al (2011), they do not consider critical thinking as a key competency, but rather as a general competency that underpin the other key competencies.

Likewise, Redman & Wiek (2021) introduced a unified framework that showed somewhat different relationship between the key competencies as articulated earlier by Wiek et al (2011). Their framework also considered critical thinking as a general competency along with creativity and learning that underpin other key competencies. They also introduced 3 new key competencies: Implementation competency (which brings together the 4 competencies of systems thinking, futures thinking, values thinking and strategic thinking), intra-personal competency (addressing need for self-awareness and self-regulation) which complements interpersonal competency, and also underpins other competencies. Integration competency is then the key competency that brings together all other key competencies for advancing sustainability transformations.

SUSTAINABILITY LITERACY, SUSTAINABILITY MINDSET AND SUSTAINABILITY MINDSET PRINCIPLES

Another seemingly parallel track under investigation with regards to ESD is the notion of sustainability literacy and sustainability mindset. Sustainable literacy appears in the literature as sustainable development literacy, literacy for sustainable development, and/or sustainability literacy. Sustainable literacy is generally conceived as an understanding of sustainability and the identification and translation of issues that have sustainability implications (Perkins et al, 2019). Ansari & Stibbe (2009) explored the concept of sustainability literacy in terms of what skills, values, attributes and dispositions would learners need to navigate their lives in the challenging conditions of the twenty first century, in relation to sustainability and well-being.

Sustainability mindset is defined as a way of thinking and being that result from a broad understanding of the ecosystem's manifestations, from social sensitivity, as well as an introspective focus on one's personal values and higher self, and finds its expression in actions for the greater good of the whole (Kassel, Rimanoczy & Mitchell, 2016). Sustainability mindset is to be developed as a new lens through which individuals can look into the world, analyzing data and making better decisions. Hermes & Rimanoczy (2018) noted that developing a sustainability mindset means engaging head, heart and hands; whereby the values, purpose, and emotions provide a holistic and deep learning experience with transformative power towards a sustainability mindset. Further effort by Rimanoczy & Llamazares (2021), who based on their work on qualitative exploratory study of what motivated leaders to champion sustainability initiatives, identified 12 elements that guides development of a sustainability mindset, grouped under 4 central areas. Table 1 showed the synthesis of these ideas.

Table 1. Sustainability Mindset – Central Areas, Dimensions and Principles

Central Areas	Sustainability Principles	Dimensions		
		Knowledge (Thinking)	Being (Values)	Doing (Action)
Ecological Worldview	• Ecoliteracy • My Contribution	Ecoliteracy	Biospheric Orientation	Protective / Restoration Practices
Systems Perspective	• Both-And Thinking • Cyclical Flow • Interconnectedness • Long-Term Thinking	Systems Theory	Inter-connectedness	Stakeholder Engagement
Emotional Intelligence	• Self-Awareness • Reflection • Creative Innovation	Self/Other Awareness	Compassion	Proactive Glocal Sensitivity
Spiritual Intelligence	• Oneness with Nature • Mindfulness • Purpose	Purpose/ Mission	Oneness with All That Is	Contemplative Practice

In terms of outcomes, Parkin et al (2004) noted that a sustainability literate person would be expected to attain the following, expressed at the highest level:

- Understand the need for change to a sustainable way of doing things, individually and collectively
- Have sufficient knowledge and skills to decide and act in a way that favours sustainable development
- Be able to recognize and reward other people's decisions and actions that favour sustainable development

DESCRIPTION OF WORK DONE FOR THIS PAPER

We had earlier shared how we used the 12 CDIO Core Standards to integrate key competencies for sustainability into the SP DCHE Curriculum as the adopted the CCC (Cheah et al (2022), and the evaluation of the effort (Oh et al 2024). The next step in the integration of ESD is to build on the effort of CCC, to continue to develop students' competencies in sustainable development, in progressively deeper coverage using with domain-specific knowledge, to further contextualize the learning using selected UNSDGs. The aim is to develop students' sustainability mindset as a key element of SP's graduate attributes. As graduate attributes are common for all students – regardless of the program – there is a need to explore a common approach whereby any program can adopt/adapt, even though each may likely integrated ESD in its own unique way.

While the pathways explored by different program may be different, they are guided by the same approach using the CDIO Framework, towards the desired outcome of transformative learning among students. Mezirow (2003) explained "transformative learning" as "learning that transforms problematic frames of reference – sets of fixed assumptions and expectations (habits of mind, meaning perspectives, mindsets) – to make them more inclusive, discriminating, open, reflective, and emotionally able to change". Scarff-Seatter & Ceulemans (2017) further elaborated that transformative learning is a process that:

(i) allows students to question taken for granted frames of reference to become more discriminating, open, and reflective
(ii) produces major changes in thinking, feeling, acting, relating, and being
(iii) allows for evaluating values and assumptions for their effectiveness towards shared goals

To achieve these desired outcomes, we noted that there is lot of complementarity between the 2 strands of work on ESD: Development of key competencies for sustainability on one hand, and development of sustainability mindset on the other. Both are like 2 sides of the same coin: The approach towards sustainability mindset is decidedly more person-centric, focusing of the belief, values, attitudes and disposition of an individual towards his/her surroundings, e.g. "My Contribution" under Ecological Worldview, and "Oneness with Nature" under Spiritual Intelligence. The emphasis is greater on the "developing awareness" and "exploring paradigm" part as shown on the right-side of Figure 1. On the other hand, the approach to key competencies of sustainability is more task-oriented, with some considerations of the individual involved in the change effort. The focus is more on the "getting into action" part of right-side of Figure 1. The elements of emotional intelligence and spiritual intelligence in particular, can reinforce the self-awareness competencies needed for integrative problem-solving. Overall, the 4 elements of the sustainability mindset principles helped to highlight the need to consider "time-scale" relationship in addressing sustainability issues.

MAPPING AGAINST SUSTAINABILITY COMPETENCIES		CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS	Systems Thinking	Anticipatory	Normative	Strategic	Collaboration	Critical Thinking	Self-Awareness
2.1 ANALYTIC REASONING AND PROBLEM SOLVING	2.1.1	*Problem Identification and Formulation*	✓✓✓	✓	✓			✓	
	2.1.2	*Formulate a Strategy to Solve Problems*	✓✓✓	✓		✓			
	2.1.3	*Analyze Results*	✓✓✓					✓	
	2.1.4	*Conclude Study and Make Recommendation*	✓✓✓						
2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY	2.2.1	*Formulate Hypothesis*	✓						
	2.2.2	*Conduct Literature Review*	?						
	2.2.3	*Conduct Experimental Inquiry*	✓						
	2.2.4	*Analyse Data and Write Report*							
2.3 SYSTEM THINKING	2.3.1	*Understand the basis and methods of system thinking*	✓✓✓		✓			✓	
	2.3.2	*Understand Interactions in Systems, and External to Systems*	✓✓✓	✓✓✓	✓			✓	
	2.3.3	*Apply System Thinking in Problem-Solving*	✓✓✓		✓			✓	
	2.3.4	*Understand Trade-offs, Synergies, Judgment and Balance in Resolution*	✓✓✓	?	✓✓✓	✓✓✓		✓	
2.4 ATTITUDES, THOUGHT AND LEARNING	2.4.1	*Demonstrate Positive Attitude and Willingness to Make Decisions in Face of Uncertainty*	✓	✓					✓
	2.4.2	*Demonstrate Perseverance, Sense of Urgency and Will to Deliver*	✓	?		✓	✓	✓	✓
	2.4.3	*Demonstrate Resourcefulness and Flexibility in Adapting to Change*	✓	?					✓
	2.4.4	*Demonstrate Creative Thinking*	✓						
	2.4.5	*Demonstrate Critical Thinking*	✓✓✓	✓	✓	✓	✓	✓✓✓	
	2.4.6	*Demonstrate Self-Awareness, Self-Reflection, Metacognition and Knowledge Integration*		✓✓✓	✓			✓✓✓	✓✓✓
	2.4.7	*Demonstrate Learning Agility, Engage in Lifelong Learning and Educating*	✓						✓✓✓
	2.4.8	*Manage Time, Technology and Resources*	✓	✓✓✓		✓✓✓			
2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES	2.5.1	*Apply Knowledge of Sound Values and Ethics, and Demonstrate Social Responsibilities*			✓✓✓		✓	?	
	2.5.2	*Demonstrate Professional Behaviour at Work and in Society*		?	?		✓		✓
	2.5.3	*Develop Self-Awareness in Life Planning*		?	?		✓		✓✓✓
	2.5.4	*Stay Current on One's Own Professional Field (e.g. Engineering, Business, etc)*	✓	✓		?			✓
	2.5.5	*Demonstrate Respect for Equity, Justice, Diversity and Inclusiveness*					✓✓✓	✓	
	2.5.6	*Exhibit Trust and Loyalty*					✓✓✓		
3.1 TEAMWORK AND COLLABORATION	3.1.1	*Form Effective Teams*					✓✓✓		
	3.1.2	*Manage and Participate in Teams*					✓✓✓		
	3.1.3	*Participate in Multi-perspective Collaboration*					✓✓✓	✓	
	3.1.4	*Engage Stakeholder, Establish Diverse Connections and Networking*		✓		✓	✓✓✓		
3.2 COMMUNICATION	3.2.1	*Design Appropriate Communications Strategy*				✓			
	3.2.2	*Design Appropriate Communication Structure*							
	3.2.3	*Demonstrate Effective Written Communication*							
	3.2.4	*Demonstrate Effective Digital Communication*							
	3.2.5	*Demonstrate Effective Graphical Communication*							
	3.2.6	*Demonstrate Effective Oral Presentation*							
	3.2.7	*Demonstrate Effective Interpersonal Communication, Inquiry, Listening, Dialog and Argumentation*			✓		✓✓✓	✓	
	3.2.8	*Demonstrate Effective Negotiation, Compromise and Conflict Resolution*			✓✓✓	?	✓✓✓	✓	
	3.2.9	*Demonstrate Advocacy*	✓	✓		?		?	?

MAPPING AGAINST SUSTAINABILITY COMPETENCIES		CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS	Systems Thinking	Anticipatory	Normative	Strategic	Collaboration	Critical Thinking	Self-Awareness
4.1 EXTERNAL, SOCIETAL AND ENVIRONMENTAL CONTEXT	4.1.1	*Identify Roles and Responsibility of Engineers or Other Professionals*			✓	✓			✓
	4.1.2	*Address the Impact of Engineering on Society and the Environment*	✓✓✓	✓✓✓	✓	✓		✓✓✓	✓
	4.1.3	*Recognise How One's Profession is Regulated in Society*	✓✓✓		?				✓
	4.1.4	*Understand Historical and Cultural Context in Engineering or Other Professions*	?		?				
	4.1.5	*Understand Contemporary Issues and Values*	✓		✓✓✓			✓	
	4.1.6	*Describe a Vision for the Future*	✓	✓	?	?			✓
	4.1.7	*Develop an International and Global Perspective*			✓✓✓	✓✓✓		?	
4.2 ENTERPRISE AND BUSINESS CONTEXT	4.2.1	*Appreciating Different Enterprise Cultures*	?		?				
	4.2.2	*Understand Different Enterprise Stakeholders, Strategy and Goals*	?		✓		✓		
	4.2.3	*Understand Technical Entrepreneurship*		?				?	
	4.2.4	*Understand Working in Local Organizations*					✓✓✓		
	4.2.5	*Understand Working in International Organizations*			?		✓✓✓		
	4.2.6	*Understand New Technology Development and Assessment*		✓		✓			
	4.2.7	*Understand Project Finance and Economics*		?	?	✓			
4.3 CONCEIVING, SYSTEM ENGINEERING AND MANAGEMENT	4.3.1	*Understand Societal and Planetary Goals and Constraints*	✓✓✓	✓	✓	✓		✓	
	4.3.2	*Understand Needs and Goal-setting*	✓	✓	✓	?			
	4.3.3	*Evaluate Function, Concept and Architecture*	✓						
	4.3.4	*Develop System Engineering, Modelling and Interfaces*	✓						
	4.3.5	*Develop a Project Management Plan*			?	?			
	4.3.6	*Develop a Product Information and Knowledge Management Plan*							
4.4 DESIGNING	4.4.1	*Formulate the Design Process*	✓✓✓		✓	✓			
	4.4.2	*Plan the Design Process Phasing and Approaches*					?	?	
	4.4.3	*Utilize Knowledge in Design*							
	4.4.4	*Understand Disciplinary Design*					?		
	4.4.5	*Understand Multidisciplinary Design*		?			?		
	4.4.6	*Design for Sustainability, Safety, Aesthetics, Operability and Other Objectives*	✓✓✓	✓✓✓		✓		✓	
4.5 IMPLEMENTING	4.5.1	*Design a Sustainable Implementation Process*	✓✓✓	✓		✓		✓	
	4.5.2	*Plan Hardware Manufacturing Process*		?			?		
	4.5.3	*Plan Software Implementing Process*		?			?		
	4.5.4	*Plan Hardware-Software Integration*		?			?		
	4.5.5	*Conduct Test, Verification, Validation and Certification*				?			
	4.5.6	*Manage Implementation Process*	?			?			
4.6 OPERATING	4.6.1	*Design and Optimizing Sustainable and Safe Operations*	✓✓✓	✓	✓	✓		✓	
	4.6.2	*Plan Training and Operations*				?			
	4.6.3	*Plan Support for Product, Process, Service, System Life Cycle*	✓			?			
	4.6.4	*Manage System Improvement and Evolution*		?		?			
	4.6.5	*Manage Disposal, Circularity and Life-End Issues*	✓✓✓			✓			
	4.6.6	*Plan for Operations Management*	✓✓✓	✓		✓			

Any cell with 3 or more (✓✓✓) will be recorded as such. Same for 3 or more (✓). Entry with mix of (✓✓✓) and (✓) will be recorded as (✓). Entry with (✓✓✓) or (✓) AND (?) will be recorded as (?). Entry with 1 (✓) and 1 or more (?) will be left BLANK.

✓✓✓ Explict / Strong ✓ Implicit / Partial

? Potential / Need for Improvement

Figure 1. Mapping between UNESCO Key Competencies for Sustainability and CDIO Syllabus version 3.0 (this work)

What we strive to do, is to harmonize these 2 threads into a unified approach towards a holistic development of ESD, guided by the CDIO Framework. We continue with the findings of the usefulness of key competencies for sustainability, which had been reported to be widely used in university masters programs by Salovaara et al, (2020).

Convergence of Key Competencies for Sustainability and Sustainability Mindset

With the release of CDIO Syllabus version 3.0 (Malmqvist et al, 2022), we have also revised our own SP-CDIO Syllabus to match that of version 3.0. In the CDIO Syllabus version 3.0, the needs and opportunities identified in Rosén et al (2019) have been further refined, and additional references were consulted and changes implemented. For our work, we adopted the same approach of Rosen et al (2019), with the 5 authors of this paper each studied the competencies and mapped them against the revised SP-CDIO Syllabus version 3.0. The outcome shown is in Figure 1. It showed that we are in good agreement with regards to the skills and attitudes that underpins the key competencies for sustainability (dark shaded box with 3 tick marks). There are some small degrees of uncertainty over other supporting skills and attitudes (light shaded box with 1 tick mark), reflecting the different perspective each author has over how direct/remote a given skill or attitude is supporting a given key competency of sustainability, probably due to varying needs of the domain-specific knowledge. Lastly, the team also surfaced some areas where improvements may be useful (non-shaded box with question mark), which again can be influenced by domain-specific knowledge.

The relationship between key competencies for sustainability and sustainability mindset principles appeared to be under-researched. Our research of the literature yielded a paper from Cripps & Smith (2023) that briefly compared the 12 sustainability mindset principles to the UNESCO key competencies, and a paper from Ansari & Stibbe (2009) that provide a list of skills and attitudes needed for sustainability mindset.

We then map skills and attitudes needed for sustainable mindset from the Ansari & Stibbe (2009) paper to sustainability mindset principles. Each of the 5 authors again did his/her own mapping using the SP-CDIO Syllabus version 3.0, and the first author then reconcile all submissions and the results is shown in the left part of Figure 2. Here we also found good match with the topics covered in the SP-CDIO Syllabus, and not surprisingly, each principle can also be mapped to many skills and attitudes. On the right part of Figure 2, we showed the skills and attitudes that mapped strongly with the key sustainability competencies – results of mapping that was showed in Figure 2 earlier. Figure 2 clearly showed that sustainability mindset principles and key competencies for sustainability are 2 sides of the same coin.

With these mapping done, we proceed to put together a framework needed. We aim to develop a framework that is not only useful for programs in SP to use, but also valuable for other CDIO collaborators. This will also help to address challenges at operationalizing competencies for sustainability as highlighted by various authors (e.g. Brundiers et al, 2021, Wiek et al, 2016, Wilhelm et al, 2019).

The CDIO Way: From Key Competencies for Sustainability to Sustainability Mindset

In this part of the development, we took notes of the apparent paradox of ESD: On one hand, much work had been done to “harmonize” what constituted key competencies for sustainability, intending these to be context-independent so that any resulting model can be adoptable by any disciplines and fields of study. On the other hand, there are challenges in operationalizing them: developing a key competency – which by definition is made up of several other (i.e. hitherto “non-key”) competencies – requires learning these set of

competencies; and such learning requires context. In fact, competencies had been described as “learnable but not teachable” (Barth et at, 2007). Competence is linked to domain and dependent on context (Vitello et al, 2021). Mochizuki & Fadeeva (2010) charged that “Competences have no meaning unless they are enacted in practice and connected to assessment in a particular context”. Likewise, sustainability education is inextricably linked to context (Sterling et al, 2017). This is a point also highlighted by Wilhelm et al (2019) who wrote on challenges operationalizing competencies for sustainable development, noted that “theoretical debates on competences insist on the fact that competences can neither be transferred nor taught, but only acquired in a specific context”.

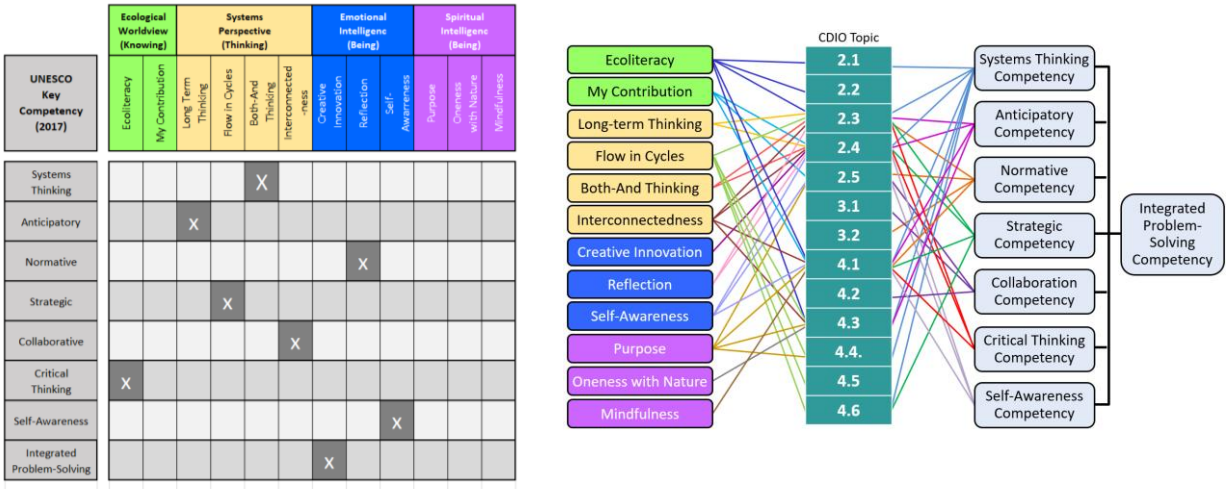


Figure 2. Aligning Sustainability Competencies to Sustainability Mindset Principles (Right: with Cripps & Smith, 2023; Left: This work via SP-CDIO Syllabus)

We build on our earlier efforts in using CDIO to integrate CCC and ESD; and added the considerations for sustainability mindset principles along with the selected CDIO Core Standards to develop the required key competencies for sustainability. We argued that the CDIO Framework will provide the “missing link” between the context-independent key competencies for sustainability, and the context-dependent development of their underpinning competencies. Most notably is Standard 1 The Context which will provide the necessary context under which a given program can used as the basis for designing ESD specific for the discipline or field of study. We further argued that the 12 sustainability mindset principles can be used to provide further guidance to the design of an integrated curriculum (Standard 3) which in turn can be imparted to students via a series of touchpoints, such as projects of increasing level of complexity (Standard 5 Design-Implement Experiences), laboratory experiments, workshops, assignment, etc (Standard 7 Integrated Learning Experiences), etc that provide actual hands-on experience to progressively develop the desired competencies over the program’s duration. The result is shown in Figure 3.

The next step is to explore concerns raised by some authors by investigating the relationship between the key competencies for sustainability with a view of “organizing” them into a form of hierarchical relationship (Brundiers et al, 2021).

Relationship between Key Competencies for Sustainability and Hierarchy of Development

Guided by the CDIO Framework, we proceed to explore the development of our own framework, we studied the previous efforts as detailed in the literature section earlier – for example the works of Brundiers et al (2021) and Redman & Wiek (2021). In particular we

focused on the challenge of formulating the hierarchy of competencies. The resulting framework is shown in Figure 4, comprising the following competencies:

- Integrated Problem-Solving Competency
- Systems Thinking Competency
- Futures Thinking Competency
- Values Thinking Competency
- Strategic Thinking Competency
- Interpersonal Competency
- Intrapersonal Competency
- Implementation Competency

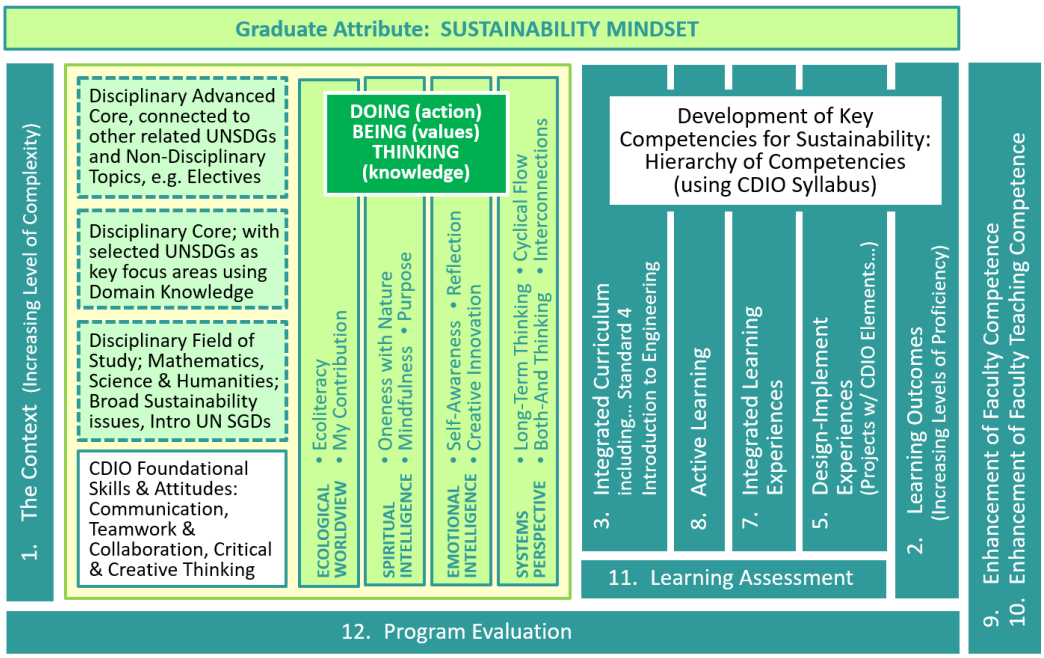


Figure 3. How Selected CDIO Standards along with Sustainability Mindset Principles can Support Development of Key Competencies for Sustainability

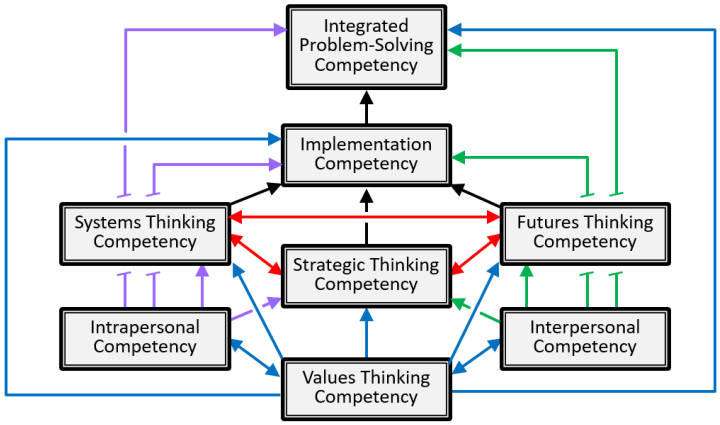


Figure 4. Key Competencies for Sustainability – Hierarchy and Possible Relationships

As a framework, the key competencies are not compiled as a list to select from; instead, all key competencies need to be integrated for advancing sustainability transformations (Redman & Wiek, 2021). The following are our key considerations:

- Values thinking competency (Wiek et al, 2015) is preferred over normative competency (UNESCO, 2017) for its emphasis on values; simply because sustainable development challenges had remained a contested and value-laden concept (Sterling, 2011, Harding, 2005). In fact, Brundiers et al, (2021) opined that it should be providing the normative orientation for the other competencies.
- Futures thinking competency likewise replaced anticipatory competency.
- Interpersonal competency will be used in place of collaboration competency from UNESCO (2017), as it broadens the engagement process to include use of communication (Genc, 2017) and applicable to a range of different stakeholders including transdisciplinary teams (Frisk & Larson, 2011).
- Intrapersonal competency will subsume self-awareness competency from UNESCO (2017), and will also include other skills and attitudes such as self-regulation, and to continually improve oneself (Brundiers et al, 2021)
- Interpersonal competency and intrapersonal competency are to underpin all other competencies (Brundiers et al, 2021; Ayers et al, 2023)
- Added implementation competency as suggested by Redman & Wiek (2021), as well as Brundiers et al (2021), although later work by Brundiers et al (2023) excluded it. We acknowledged that this is still a contested area. For example, it can be argued that implementation skills is part of the overall problem-solving process. We are agreeable to include it for the reason that it distinguish itself from other key competencies in its focus on “doing” that leads to integrated problem-solving.
- We agree with the views aired by Brundiers et al (2021) and Redman & Wiek et al (2021) that critical thinking is not considered a key competency. Rather, these authors opined that critical thinking is a basic academic competency developed in any educational program.
- All key competencies in sustainability are referenced as a framework as they are interdependent; each contributes its part to sustainability problem-solving processes (Brundiers et al, 2021).
- Lastly, and most importantly, we suggest that – in terms of the “quest” for a hierarchy of key competencies – there is more than one way to structure the various key competencies bounded by values thinking competency and integrated problem-solving competency,

Values thinking competency is considered the underpinning competency that holds together all other key competencies. It particularly had a strong influence over interpersonal and intrapersonal competencies; and collectively they guide the development of the next 3 key competencies, namely: strategic thinking, future thinking, and systems thinking; which in turn, drives the implementation competency leading to the integrated problem-solving competency.

In our model, we argued that these 3 key competencies (strategic thinking, future thinking, and systems thinking) mutually influence one another when addressing sustainable development issues; and often requires several iterations (shown as double-headed arrows in Figure 4) to arrive at an optimal solution before proceeding to the implementation stage. Hence, we suggested that the competencies suggested by Kassel et al (2016) pertaining to the “Doing” dimension of Sustainability Mindset – notably Proactive Glocal Sensitivity (under the area of Emotional Intelligence) and Protective/Restorative Action (under Ecological Word – should be considered specific areas to be addressed by the integrated problem-solving competency. Similarly, the Stakeholder Competency under Systems Perspective and Contemplative Practices under Spiritual Intelligence (Kassel et al, 2016) and be examples of specific areas under interpersonal competency and intrapersonal competency respectively. We argued that the formulation of these strategies should synergistically and simultaneously involve several key competencies for sustainability – strategic, systems thinking and futures thinking – depending on the nature of sustainability issue to be addressed.

DISCUSSION

We acknowledged that the search for key competencies will continue unabated. We believe our model is a first of its kind that attempted 2 things. The first is to reconcile the theoretical underpinning of sustainability mindset principles to the development of key competencies for sustainability. This is achieved via the use of CDIO Syllabus. The second is to operationalize the key competencies for sustainability using the CDIO Standards.

Taken together the CDIO Framework enable us to arrive at a plausible approach to integrate ESD into any educational program; by leveraging on the context-independence nature of key competencies for sustainability that "translate" (via the CDIO Standards) the more generic competencies (from the CDIO Syllabus) into context-specific scenarios where disciplinary knowledge is used alongside skills and attitudes to address sustainability issues. We believe this approach will help to reconcile the decontextualized nature of key competencies which are meant to drive curriculum design on one hand, and the necessity for context to be integrated when operationalizing these competencies. As noted by Ploum et al (2017): "Sustainability challenges and tasks often become meaningful in one's specific work environment".

Grounded solidly in the CDIO Standards, Figure 3 serves as a useful starting point for any program owner to consider how best to utilize the courses within the given program to develop students' sustainability mindset. Figure 4 provides broad guidance to structure the skills and attitudes development needed for key competencies for sustainability, emphasizing the development of skills, in a progressive manner over the program duration. For example, underpinning knowledge to be covered in year 1 (not exhaustive) would include: (2.4.5) *Demonstrate Critical Thinking*, especially in teamwork and collaboration, e.g. (3.1.2) *Manage and Participate in Teams*, (3.2.1) *Design Appropriate Communication Strategy* and (3.2.2) *Design Appropriate Communication Structure* (3.2.2), and values and attitudes such as (2.5.5) *Demonstrate Respect for Equity, Justice, Diversity and Inclusiveness*, (4.1.1) *Identify Roles and Responsibility of Engineers or Other Professionals*, (4.1.5) *Understand Contemporary Issues and Values*. The build-up will continue in subsequent years of study, for example (4.1.7) *Describe a Vision for the Future*, on to (2.4.2) *Demonstrate Perseverance, Sense of Urgency and Will to Deliver* and (2.5.6) *Exhibit Trust and Loyalty* etc.

We had earlier suggested that, based on Figure 4, after building up students' values thinking, interpersonal and intrapersonal competencies, a program can pursue different pathways to continue to build up students' strategic thinking, systems thinking and futures thinking competencies; instead of following a specific sequence. This can be based on specific nuances of the program seeking to integrate these competencies; for example, facility constraints, sequencing of courses, etc. Furthermore, different program may need different proficiency levels for different key competencies. For example, Wiek et al (2011) noted that key competencies would hold varying degrees of relevance to different cultural and academic contexts. Likewise, Mochizuki and Fadeeva (2010) commented that it is important that individual programs formulate their own competencies together with strategies for achieving these (Missimer & Connell, 2012; Brundiers & Wiek, 2017; Downs et al, 2017).

Figure 5 showed a hypothetical example of how the framework of Figure 4 can be operationalized, guided by the mapping between the SP-CDIO Syllabus version 3.0 and the underpinning skills and attitudes needed for key competencies for sustainability.

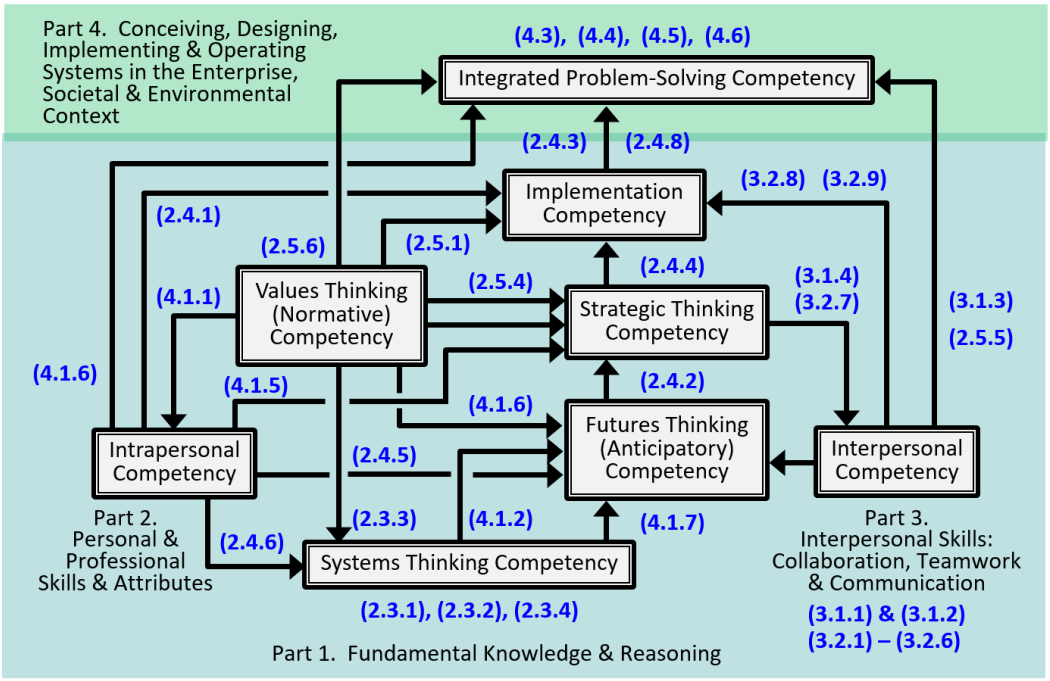


Figure 5. Possible Development Pathway to Integrated Problem-Solving Competency

In this manner, the model afforded program owner with the flexibility to sequence the development of strategic thinking, systems thinking and futures thinking competencies that best meet the program's overall learning outcomes. This approach also helped to avoid the dilemma of sequencing them in a rigid manner.

An example application of the model is provided by Yang & Cheah (2025), who shared how the suggested approach can be operationalized for the chemical engineering program, that had adopted the CDIO Framework as the basis for its curriculum redesign. The authors firstly established the relevant UNSDGs that the program seek to address, by conducting a gap analysis of coverage of selected UNSDGs following the adoption of the SP CCC. Ascertain the program's key competencies for sustainability needed to address the sustainability issues for the selected UNSDGs, and the required proficiency levels of each. The program then leverage of the foundational skills and attitudes already developed via the SP CCC, and identify core modules to further deepen the required proficiencies using the CDIO approach. A development pathway can then be designed that progressively develop the required proficiencies, using the underpinning skills and attitudes such as critical and creative thinking, teamwork, collaboration and communication, ethical reasoning, etc.

Usefulness of the Model

We believe our proposed model is useful in addressing the risk of key competencies for sustainability being compiled into a "laundry list" as other authors/researchers proposed new items based on their work. This can be illustrated with an example. A new entry termed "transboundary competence" is suggested by de Kraker et al (2007) for transdisciplinary collaboration to address sustainability issues. By inspecting the underlying skills and attitudes for the competency, we argued that this competency can be considered part of interpersonal competency – an "existing" key competency for sustainability, rather than a new, separate key competency. In this manner, the model (Figure 3) offers us the flexibility to continually refine it as "new" competencies were proposed; and the interrelationship between the competencies clarified (Figure 4).

As another example, Brundiers & Wiek (2017) called for the inclusion of a set of professional competencies with 6 domains, namely collaborative teamwork, effective and compassionate communication, responsive project management, advanced continuous learning, preventative self-care. The process outlined in this paper can provide guidance on where and how the set of professional competencies can be situated.

During the course of our effort to investigate the relationship between the key competencies for sustainability, we also came across various publications where specific work context is highlighted to derive competencies needed for a particular job role. Examples include entrepreneurship (Ploum et al, 2017; Lans et al, 2014), and research (Venn et al, 2022; Lambrechts & Van Petegem, 2016), where the respective author(s) suggested that these are competencies needed for work-related sustainability, and henceforth should be included in the list of competencies for sustainability. Venn et al (2022) also proposed a new, overarching sustainability intervention competency for sustainability professionals – defined as professional practitioner who secures his/her livelihood by contributing to sustainable development and taking stewardship for the profession – which consists of interpersonal collaboration competency, capacity building competency, intrapreneurial competency, strategic competency, political competency and implementation competency. These authors argued that the experience of practitioners who successfully operated in the field of sustainability is valuable, since it transcends the perspective of students and educational experts. This can help to mitigate the risk of gaps between what is taught in higher education and what is needed in practice.

Hence, despite the apparent convergence, there remained challenges as new articles appeared that calls for more “new” competencies to be added. This will once again run the risk of creating another “laundry list”, but now it is for key competencies for sustainability! This is perhaps unavoidable, given the complex and cross-cutting nature of competencies needed to address sustainability challenges. Coupled with the diverse conceptualizations of competencies, it is impossible to capture and define the required competencies for sustainability (Mochizuki & Fadeeva, 2010). Wilhelm et al (2019) charged that because of the fundamental context-boundedness of competences, trying to compare competence models developed in different contexts and based on different understandings of the role of education does not make it possible to answer the following question: “What competences are key competences for sustainable development?”

While we agreed that these work-related competencies are definitely necessary for the specified job role, whether they can be considered key competencies is debatable. Mochizuki & Fadeeva (2010) noted that “we need a democratic, deliberative and situated process of first specifying desirable competences (by asking whose needs and desires are being addressed for what purposes in what kinds of world) and then carefully articulating them in educational programs. Along this line of reasoning, we posit that the “work-related” competencies (e.g. entrepreneurship, research) are still generic in nature – much along the line why critical thinking is considered a generic competency – and applied in the CONTEXT of the job requirements.

Limitation of Our Work

We did not systematically search for publications related to key competencies for sustainability. We rely on seminal contributions from Barth et al (2007), Frisk & Larson (2011), and Wiek et al (2011, 2015) as starting point. We looked up the cited references from these articles to gain better understanding of work done.

For more recent publications, we relied on Google Search, using returns from various databases for the articles, rather than systematically searching for articles using Web of Science, SCOPUS, ScienceDirect and the like. We also did not apply any search criteria to refine the entries returned by Google Search. Instead we just read the abstracts and continue to read the full paper if its abstract looked promising; and we made a call on whether an article is to be included in our study or otherwise. We acknowledged that we could have missed out important articles that was not found by Google Search.

Another limitation is that our literature search omitted publications related to *sustainability science*, to explore its relationship with sustainability mindset and sustainability competencies. The name sustainability science implies that it is a science of sustainability – a scientific effort specifically oriented to produce sustainability, as compared to basic sciences which can be utilized to advance sustainability, i.e. science for sustainability (Spangenberg, 2011). Today sustainability science is usually understood as research providing the necessary insights to make the normative concept of sustainability operational, and the means to plan and implement adequate steps towards this end (Spangenberg, 2011).

Moving Ahead and Future Works

Our analysis of underpinning skills and attitudes for competencies for sustainability did not cover the "extended" section of the CDIO Syllabus, namely Leadership, Entrepreneurship and Research. As noted above, our current position is to consider these as generic competencies that can be adapted to the work-related context; rather than key competencies for sustainability per se.

At the time of this writing, each of the 4 diplomas had respectively embarked on developing sustainability mindset of their students in selected module(s). Each diploma is at a different stage of introducing key competencies for sustainability using the approach outline in this paper. Other works that can further enhance the current integration efforts include:

- Deep dive into the literature on sustainability science, to better understand how this emerging discipline can further strengthen the integration of key competencies for sustainability into a program
- Evaluation of students learning experiences
- Assessment of development of sustainability mindset

There is also a need to strengthen the linking of sustainability mindset principles to key competencies for sustainability. Our harmonization effort between the 12 sustainability mindset principled and CDIO Syllabus (Figure 2) revealed, perhaps not surprisingly, that the "weakest link" appears to be more on the "inner transition" aspects of the persons whose sustainability mindset we wished to develop. Many of the underpinning skills and attitudes need to be inferred from the CDIO syllabus; as they are largely written from the perspective on requirements of job roles or task requirements. Intrapersonal competency is a relatively new concept being added to the ESD literature, which increasingly turn to an individual's inner dimension and how it affects one's view on sustainability issues (Frank, 2021). It can be argued that without the transition of the self, one cannot be the change agent (Ayer at al, 2023) that advocates for the needed transformation towards a more sustainable world. As argued by Libertson (2023), lack of satisfactory progress in sustainable development can be due to a disconnect between the self, others and the environment. There is a need to revisit the mapping as more research on this topic emerges; and how to develop them in students.

Lastly, there is also a need to address the continuing professional development for the rest of our colleagues; when the development of sustainability mindset is cascade to more programs in SP. Following the United Nations Economic Commission for Europe, Wals (2014) suggested the use of ESD Competence as the educators' capacity to help others, referring to competence to facilitate the attainment of the key competencies for sustainability in students, through a range of innovative teaching and learning practices.

CONCLUSIONS

This paper synthesized the research from sustainability mindset principles and key competencies for sustainability to formulate an approach to integrate sustainable development into any educational program, based on the reasoning that sustainability mindset drives the empowerment of students to take positive actions to address sustainability issues; using a set of key sustainability competencies. The CDIO Framework is used to operationalize the key competencies for sustainability to progressively develop students' sustainability mindset via a model, that addresses current discourse on what constituted key competencies for sustainability and the need to arrange them in a hierarchical manner. Our model suggest that one first develop the values thinking competency with the end goal of developing integrated problem-solving competency. The model afforded the flexibility of each program to development of other key competencies consistent with the needs of the program. The usefulness of the model is discussed, notably how it can allow for new key competencies to be evaluated on the basis of the intent based on the CDIO Syllabus, if one to be added or subsumed into existing key competencies; to avoid generating a "laundry list" of key competencies.

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LEARNING FROM DELIBERATE FAILURE: A HOLISTIC APPROACH USING THE CDIO FRAMEWORK

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ABSTRACT

This paper presents the outcomes from 2 runs of the Working Group on Learning from Deliberate Failure from 2 successive International CDIO Conferences: first in 2023 and another in 2024. This paper outlines a holistic approach based on the CDIO Framework to the development of failure-tolerant mindset among students. We believe this paper is the first of its' kind to offer a comprehensive set of design principles that provide guidance to faculty interested in engaging students in learning from Deliberate Failure. The purpose is to assist in the design of a series of learning tasks that had “failure elements” built-in (hence the term “deliberate failure”) so that students can become more receptive towards accepting failure as a way of learning. This paper first briefly summaries outcomes from earlier work where we highlighted that there exist 2 seemingly polar extremes of learning from failure: one that seeks to promote innovation (such as in product design) via frequent exposure to failure where frequent experimentations are encouraged so as to improve with every iteration; and another that strive to avoid failure at all costs, for example, in operating complex systems such as nuclear or chemical plants. For the latter, learning from failure is achieved through case studies of past failures or from simulation of known failure events. This is followed by a literature review on design principles. We then proposed a holistic approach that faculty can use to design learning tasks for learning from failure. The approach is holistic in 2 ways: First it comprehensively covers all aspects of students learning experiences, for a transformative change in their mindset on failure, from the initial appreciation of failure’s role in promoting learning to the eventual embrace of failure as an experience that is to be welcomed; to be achieved through a range of design principles appropriate for various stages of the transformative process. Secondly, the approach is holistic in that it also provides guidance on how faculty can facilitate the learning process, for example using autonomy supportive teaching, and role-modelling. This paper concludes with discussion on limitations of the approach, and possible future work notably in the areas of assessment of learning.

KEYWORDS

Deliberate Failure, Design Principles, CDIO Standards 1-12

BACKGROUND INFORMATION IN BRIEF

The work to investigate ways to better prepare students to learn from deliberate failure stemmed from efforts by the authors – from Singapore Polytechnic (SP) and Singapore University of Technology & Design (SUTD) – to understand the impact of digitalization on students' perception of mastery in their job roles. In the competitive and high-stakes educational system, fostering creativity and innovation requires a deliberate shift in pedagogical approaches to normalize and leverage failure. This is critical for equipping students to navigate the complexities of modern industries, where resilience and adaptability to setbacks are indispensable Subsequent studies by the authors and other colleagues in SP and SUTD, and via a Working Groups on Learning from Deliberate Failure at the 2023 International CDIO Conferences (Cheah & Willems, 2023) yielded the following insights:

(1) Learning from failure can largely be categorized into 2 different threads, based on the intended outcomes: (a) to promote product innovation, which is by far the common use of learning from failure, where one is encouraged to "fail fast, fail early" that leads to improvements in the next product iteration; and (b) to maintain operational stability in complex systems (such as chemical plants), by avoiding process upsets that leads to production issues, or worse in creating safety hazards.
(2) Learning from failure for case (b) remained an under-researched area. Failure in this regard is undesirable and is to be avoided at all costs. The dominant approach here is based on case studies of previous failures, and to a lesser extent, through simulation exercises based on typical (i.e. known) failure scenarios. This approach has its limitations in today's digitalized world (Cheah, 2023) but is beyond the scope of this paper.

The authors also noted the use of failure as an approach to engage students in learning still lacked a unifying approach (Tawfik, et al, 2015; Jackson, et al, 2022). Based on these findings, subsequent research in these areas was then split into 2 threads: Case (a) is led by SUTD to explore interventions that build up students' failure tolerance in product innovation, as they continue to learn from earlier mistakes to improve on the next product design cycle; and Case (b) is led by SP to explore how the CDIO Framework can be used to guide the redesign of existing integrated learning experiences or design new ones to better prepare students in dealing with process upsets in complex systems, to prevent operational failure. The focus on deliberate-learning-from-failure addresses the gap in preparing students not just for academic success but for real-world challenges, enhancing their ability to innovate within evolving digital and industrial landscapes.

Despite their markedly different approaches, both threads shared a common trait in that failure is inherent in both innovation activities (Baxter et al, 2023; Edmondson, 2011; McGrath, 2011) and in complex systems (Edmondson, 2011). Both strive to change students' mindset to move it away from fearing of failure to one that embraces failure. We introduce the term "unsuccess" to communicate to students they had not failed in their efforts – it is that they have "yet-to-succeed". This is similar to descriptions used by various authors, for example, embracing "constructive failure" (Clifford, 1984), "non-successes" (Covington, 1992), "small losses" (Sitkin, 1996), and "temporary failures" (Alif, et al, 2004). Our concept is shown in Figure 1, whereby with suitable interventions administered over several periods of study, the mindset will gradually migrate from "unsuccess" to "success".

At the 2024 International CDIO Conference, Willems et al (2024) presented work from SUTD for Case (a) while Cheah, et al (2024) presented work from SP for Case (b) using an approach he developed for learning from failure for chemical process plant operations using the CDIO Framework (Cheah, 2023).

At the same 2024 conference, the authors conducted the second Working Group for Learning from Deliberate Failure, which sought to synthesize a set of design principles to guide faculty in designing of learning tasks that engage students to learn from deliberate failure. This paper is the outcome of these works.

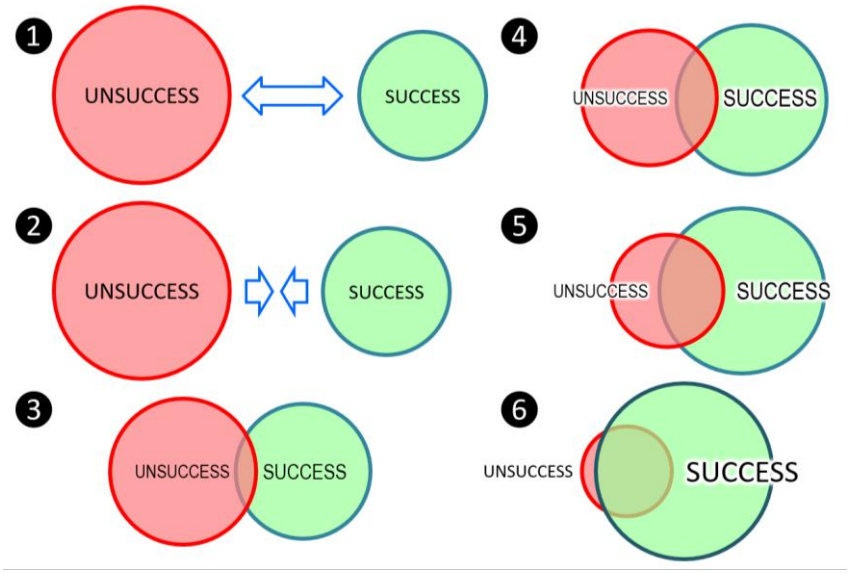


Figure 1. Changing of Mindset from ”Unsuccess” to ”Success”

SCOPE OF THIS PAPER

The relative pros and cons of learning from failure is still hotly contested (Eskreis-Winkler & Fishbach, 2022; Thiel & Semrau, 2022; Rhaiem & Amara, 2021; Madsen & Desai, 2010; Baumard & Starbuck, 2005; Van der Panne et al, 2003). This paper takes the position that it is beneficial to learn from failure, provided that the learning process is well-managed through a series of thoughtful design of learning interventions so that the desired change – i.e. acceptance of failure as a source of learning – can occur.

The needs to have a set of design principles is recognized when our efforts as reported above showed that there is a lack of research into the systematic design of interventions to better prepare students to embrace failures and see them as opportunities of learning especially in the case of operation of complex systems. By having a holistic and coherent approach, we hope to avoid what Feigenbaum (2021) called “Dissonant Paradigms of Failure in Higher Education” when we tell students it is acceptable to fail but our actions showed otherwise.

This paper presents an approach that we believe is a first of its kind to provide guidance on how to shift students’ mindset from fearing failure to one that embraces it, through a series of CDIO integrated learning experiences, created based on various design principles depending on which aspect of change (see Table 1 later) is targeted. As changing students’ mindset on failure is a complex, multi-faceted challenge, we suggest that using a design-based approach may be a viable way for faculty to iterate on the intervention efforts with “built-in” elements of deliberate failure to achieve the desired mindset change. In particular, VanLehn et al (2003) noted that learning did not take place despite instructor guidance of a concept if the students did not reach an impasse during the learning process.

“Deliberate Failure” in this context of this work means that educators can deliberately design learning activities with elements/difficulties that will lead to students encountering challenges to complete the prescribed task, i.e. “failure”. Such an approach would be equally applicable for both Cases (a) and (b) mentioned earlier. The differences lie in the choice of design principles to be used depending on the desired outcomes of the intervention, as some may be more suited for Case (a) as opposed to Case (b) and vice versa.

As such, this paper proposes a holistic approach in designing for deliberate failure using the CDIO framework as a basis. We thus synthesize prior work on learning from failure published within as well as beyond the CDIO tradition (e.g. Cheah, 2023; Foley et al., 2022; Huang et al., 2023; Willems et al., 2024). Below, we first expand on our choice for using design principles for this paper, after which we detail how these map onto the CDIO framework. We end the paper discussing the implications of our work.

WHAT ARE DESIGN PRINCIPLES?

Design principles are considerations that can be used to guide the design and development of learning environments in higher education that are based on sound practical and theoretical principles, and that can promote student engagement through innovative learning tasks. They exist in a range of different contexts, and they enable teachers and instructional designers to use well-researched ideas as guidelines for their own efforts to enhance student engagement and learning outcomes (Herrington & Reeves, 2011).

Van den Akker (1999) described design principles as heuristic statements in a format best illustrated as follows:

> *If you want to design intervention X [for the purpose/function Y in context Z], then you are best advised to give that intervention the characteristics A, B, and C [substantive emphasis], and to do that via procedures K, L, and M [procedural emphasis], because of arguments P, Q, and R. (pp.9)*

McKinney, et al (2006) cautioned that such design principles are not ”recipes for success” but are used principally ”to help others select and apply the most appropriate substantive and procedural knowledge for specific design and development tasks in their own settings”. Likewise, Herrington & Reeves (2011) reminded that it is unwise to consider design principles to be ”set in stone”. Instead, the authors suggested that they are best regarded as informed reusable guidelines for others wishing to create their own solutions to educational problems across sectors.

Table 1 shows a summary of design principles we proposed for designing integrated learning experiences for learning from deliberate failure. It expanded quite considerably the earlier work of Tawfik et al (2015). Following Carlson & Fishbach (2024) who noted that a key challenge of learning from failure is that extant research tended to be siloed to particular fields; hence our search covered a wide range of disciplines from education, psychology, organizational behavior, medicine, etc. The design principles are classified into various dimensions based on the type of outcomes each approach aims to achieve. Due to page limitations the respective design principles cannot be discussed in detail in this paper.

Table 1. Design Principles for Learning from Deliberate Failure

Design Principles	How it Work
Dimension: *Awareness of Failure*	
Define conditions for failure (Tawfik et al, 2015)	• Students are primed to investigate failure-states, through prompting to address the conditions for success and failure before problem-solving. • Use of failure-based question prompts, as learners may not fully understand the variables associated with a given failure scenario; hence a prompt can help in consideration of plausible scenarios and recognize potential misconceptions
Preparing the Mind: Visualization of Tasks (Cheah, 2023)	• In the context of the work of Cheah (2023), which concerns the process operation of chemical plants, this means getting students to study a given process (including the standard operating procedures) and identify areas where potential failure(s) can occur
Dimension: *Identify Consequences*	
"Learning from Disasters": Case Histories of Failures	• Cheah (2023): Traditional approach in the chemical processing industries – Learning from Disasters: making the connections between causes and consequences of an accident
Taxonomy of Failures (Young, 2019)	• Velikova et al (2018): Such taxonomy can help to establish the relationships between causes, failure symptoms and long-term consequences and improve understanding of failure • Narduzzo & Forrer (2024): A 2x2 typology of failure based on intentionality and the learning effect
Dimension: *Inquiry into Failure*	
Sense-making (Weick et al, 2005)	• Weick et al (2005): Sense-making is the process of determining how an event came about, an answer to the question "What is the story?" • Cheah (2023): Interactions between components, esp. for complex systems, with focus on relationships between process variables - Rumsfeld Matrix: Unknown Knowns
Trigger Thinking (Jackson et al, 2022)	• Theme 3 (*Failure as a mechanism to uncover key concepts*): Students first made aware of their failures, students to identify and reconcile their misconceptions… leading to: • Theme 4 (*Failure induce thoughtfulness in problem solving*)
Productive Failure (Kapur, 2015)	• It is an instructional approach that requires learners to struggle as they attempt to generate solutions to problems before, rather than after, receiving direct instruction on a targeted concept
Elaboration Prompts (Liobl & Leuders, 2019)	• Students explicitly prompted to make comparisons of correct and incorrect examples after problem solving (In general, prompts are questions or hints that aim to increase the likelihood that learners will engage in specific learning activities or give certain answers or self-explanations)
Desirable Complexity (Foley et al, 2016) based on Axiomatic Design (AD) Theory	• Using notion of "AD inverted" to "reverse engineer" selected elements of a learning task that were identified to offer opportunities for students to learn from failure. But need to be careful here though: not to make a task unnecessarily complex for the sake of making students make mistake!
Dimension: *Reflection on Learning*	
Different Perspectives on Failures	• Edmondson (2011): Blameworthy to Praiseworthy – Spectrum of Reasons for Failure • Jackson et al (2022) Theme 1 *Varied Meanings of Failure* – Process vs Solution-Oriented • Negative Knowledge (Gartmeier et al, 2008): Reflection on knowledge acquired experientially on what is wrong and what is to be avoided during performance in a given work situation • Dorland (2023): Use design thinking to reorient students' conceptions of failure as part of their creative problem-solving skill development process

Table 1. (cont'd)

Failure Stories	• Remove the Ego (Eskreis-Winkler & Fishbach, 2022): Cognitive Distancing, i.e. adopt a third-party perspective to think of one's own failure • Self-Talk (Kross et al, 2016): Small shifts in the language people use to refer to the self as they engage in this process consequentially influences their ability to regulate their thoughts, e.g. more receptive to learn from failures • Bledow et al (2017): Learning from others' failures
Systematic Reflection (Ellis et al, 2014)	• It is a learning procedure during which learners comprehensively analyze their behavior and evaluate the contribution of its components to performance outcomes; through a process of self-explanation, data verification and feedback
Dimension: *Accept/ Embrace Failure*	
Destigmatized Failure: Failure as Generative (Feiganbaun, 2021)	• Failure represented as temporary, healthy, and integral components of any learning process • Students learn more profoundly in the long term when they struggle more in the short term
Active Acceptance (Schwarz & Bouckenooghe, 2021)	• Organizations respond to failure by actively repositioning the failed outcome as success, by repositioning the criteria for what is success (e.g. by recasting what was achieved) in order to move forward, enabling organizational learning from failure
Intelligent Failure (Sitkin, 1996) as means to promote innovation	• Sitkin (1996): It results from thoughtfully planned actions that have uncertain outcomes and are of modest scale, are executed and responded to with alacrity, and take place in domains that are familiar enough to permit effective learning
Dimension: *Develop Confidence*	
Growth Mindset (Dweck, 2006)	• Eckstein et al (2023): Failure Pedagogy – Teach students about developing a growth mindset • Shahagun et al (2021): The Growth-Mindset Teaching (GMST) pedagogy as a learning opportunity and participants can feel safe to learn, re-learn, and explore knowledge without the fear of being wrong • Willems et al. (2024) on the role of encouraging an iterative mindset in stimulating innovation and design-thinking
Opportunities for Transfer	• Teaching Others – The Protégé Effect (attributed to Jean-Pol Martin in the 1980s) is a concept in learning suggesting we learn more effectively by teaching information to others, even if those others aren't necessarily any less knowledgeable
ACROSS ALL DIMENSIONS: *Teacher-Student Relationship*	
Student Reaction to Failure	• Henry et al (2019): Failure Mindset Coping Model – to help understand how students might approach challenges and respond to failures in undergraduate STEM learning contexts
Supportive Learning Environment	• Jackson et al (2022) Theme 2 *Student Reactions to Failure* and Theme 5 *Classroom Climate and Communications about Failure:* teachers need to foster a classroom culture that embraces failure and learning together • Eckstein et al (2023): Failure Pedagogy – Teacher Vulnerability: share your own failures with students • Narla (2022) Teaching to Fail: Create a vulnerable learning community • Foley et al (2022): Non-Violent Communication by Rosenberg (2015) • Bury & Masuzawa (2017): Non-Hierarchical Learning
Autonomy-Supportive Teaching (Reeve & Cheon, 2021)	• Adoption of a student-focused attitude and an understanding interpersonal tone that enables the skillful enactment of 7 autonomy-satisfying instructional behaviors (ASIBs)

Table 1. (cont'd)

ACROSS ALL DIMENSIONS: Faculty Professional Development	
Temporary Failure (Alfi, et al, 2004)	• Teacher education to address the difficulty of some teachers in allowing students to experience any kind of failure, not even temporarily; thus their willingness to challenge their students
Deliberate Reflection (Laksov & McGrath, 2020)	• Focuses on failure as catalyst to improve academic development work, through exploration and analysis of failure in one's practice, and discussion among peers • Vedder-Weiss et al (2018): Product framing of pedagogical failures – teacher sharing of learning experiences
Teacher Modelling (Wong & Cheah, 2022)	• Teacher demonstrating growth mindset, and other coping mechanisms, for example, arising from own failure • (The reference summarizes a literature review of teacher modelling using the context of developing self-directed learning competency in students)

PROPOSED HOLISTIC APPROACH TO LEARNING FROM DELIBERATE FAILURE

We argue that a holistic approach is needed so that students can most benefit from learning from deliberate failure. This is because the impact of failure can be so demoralizing that students may withdraw from the learning process altogether. Much has been written about the debilitating effects of failure that we will not repeat here (for a more recent discourse on this topic, see for example Edmondson, 2023; Eskreis-Winkler & Fishbach, 2022).

Based on the typical CDIO approach of progressively developing desired graduate attributes over a given program's duration, a similar way of inculcating failure-tolerant mindset among students can be articulated. An example used by Cheah (2023) is shown in Figure 2 below.



Figure 2. Pedagogy for Learning from Failure

Briefly, the 3 stages (each with 2 dimensions) can be explained as follows:

- *Awareness of Failure and Identify Consequences*: This means that students become aware of potential failure situation(s) before embarking on a given task. This is to be achieved via a deliberate process of getting them to visualize possible failure scenarios. They are then asked to explain plausible consequences. We are not looking for right or wrong answers at this stage. This is to "sensitize" them that "things can and will go wrong!".
- *Inquiry into Failure and Reflection on Learning*: This means that students are able to adopt an open mind and inquisitive stance to look into causes of failure and reflect on the learning. The main focus here is to let students see the possible learnings that can be gained; and metacognitive also think about how to improve on identifying plausible scenarios that were missed.
- *Embrace Failure and Develop Confidence*: This means that students recognize positive lessons that can be learnt from failure scenarios; and are able to derive key insights from such learning that they can apply the learnings gained in a given setting to other contexts.

Figure 3 represents our holistic approach towards developing failure-tolerant mindset among students. It shows how the integrated curriculum (CDIO Standard 3) can be used to progressively drive the desired transformation towards a failure-tolerant mindset, consistent with the pedagogy shown in Figure 2. This is shown as a series of learning outcomes (CDIO Standard 2). This is achieved through a series of design-implement experiences (CDIO Standard 5) and integrated learning experiences (CDIO Standard 7), focusing on real-world work environment for student engagement (CDIO Standard 1). The figure also highlights the importance of maintaining constructive alignment, where the attainment of desired outcomes via design-implement experiences and integrated learning experiences are checked using appropriate assessments (CDIO Standard 11). Lastly, faculty professional development is implied in the use of various design principles and teacher-student interactions (CDIO Standards 9 and 10).

DISCUSSIONS

The approach as shown in Figure 3 highlights that failing is a process, not an end point. We must allow for failure, and in order to learn from our failure, we must work on it (Litts & Ramirez, 2014). This paper introduces a repertoire of design principles at each stage of the transformative process, to aid the design of various learning interventions. The desired outcomes can be discerned from the CDIO Syllabus, most notably *Part 2.4 Attitudes, Thought and Learning*, as shown in Appendix 1.

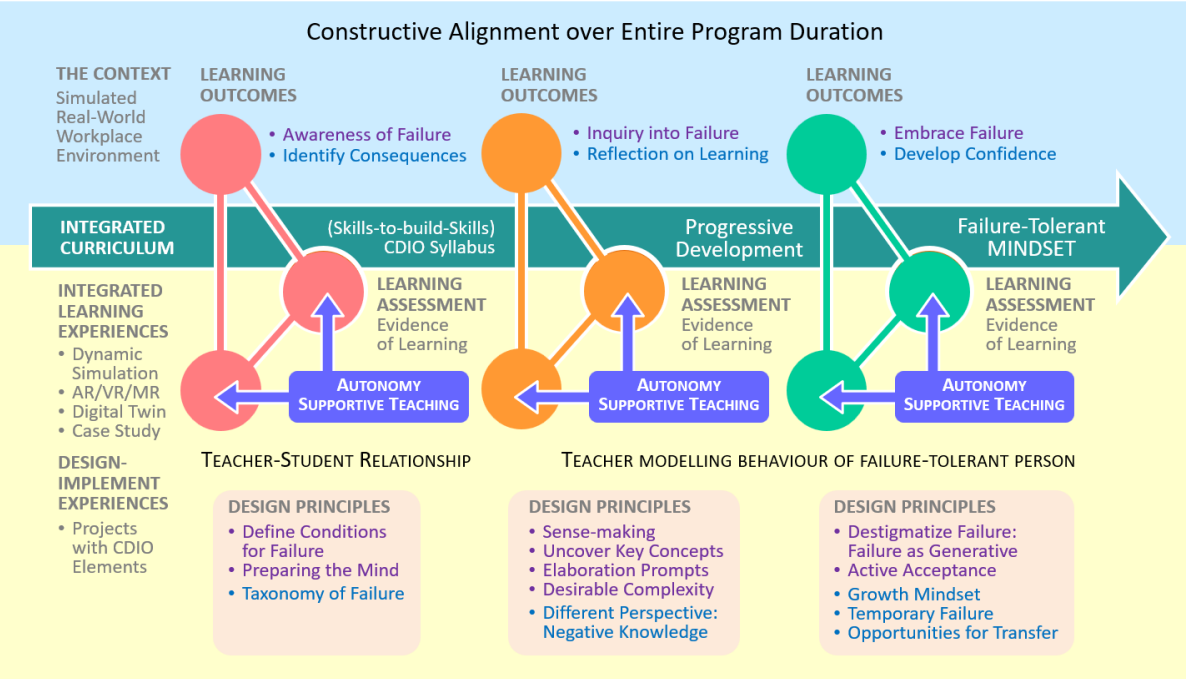


Figure 3. Approach to Develop Failure-Tolerant Mindset using CDIO

Our suggested approach is holistic in two ways. First, it comprehensively covers all aspects of students learning experiences, from firstly to initiate a mindset change to the development of failure-tolerant mindset. Second, it also provides guidance on how the desired mindset can be attained, through a range of tasks from the design and delivery of the curriculum, assessment and faculty professional development on how to facilitate the learning process, for example using autonomy supportive teaching, and role-modelling.

Table 1 is not meant to be a laundry list of all design principles that lecturers must use. There are certainly overlaps between some of the design principles, as different author(s) used a different terminology to describe one's proposed intervention. It is more like a toolbox where faculty pick the suitable design principles that match the desired aspect(s) of mindset change desired, in the design of appropriate learning interventions. It is also possible that using one design principle may have more than one effect on students learning. For example, systematic reflection can help in destigmatizing failure and promote growth mindset. Hence, it is reasonable to expect that a single learning intervention may concurrently employ several design principles within the same learning context.

We also deliberately omitted the use of game-based learning or gamification as design principles. The rationale for the omission is as follows: Usually the term "serious game" is used to describe games designed for educational outcomes as opposed to those designed for entertainment. For games to be of educational and aid students, they must focus on the content to emphasize theories to be learnt and should therefore be developed by scholars and teachers and be based on good academic philosophies (Adipat et al, 2021). However, often times the teachers' pedagogical expertise does not directly translate into game design, and it leaves educators puzzled regarding the effective ways to introduce learning games in a class and what elements of games and learning should be prioritized (Kucher, 2021). Studies by Chase et al (2021) showed that some common features can hinder students' failure tolerance, challenge-seeking and learning. Furthermore, recent research also highlighted that although there is agreement that games have educational potential, the assumption of blanket learner enthusiasm for game-based learning is not always accurate; and students have some resistance towards serious games, which are seen as less appealing than "real" video games (Persico et al, 2018). Other reasons include perception that serious games have lower production values (e.g. style, realism, color) than entertainment games; and that gaming as a voluntary, self-driven activity, is at odd with the structured nature of school (Passarrelli et al, 2019).

Limitation of This Study and Approach

While we tried to include in our coverage as many dimensions for the design principles as warranted, we acknowledge that Table 1 is not exhaustive. Many of the design principles are summarized from studies of organizational learning, which we believe are extendable and can be contextualized for promoting students' learning from failure. Such assumptions need to be tested out.

We also did not include analysis of factors that affect students' dispositions toward failure, although there is scholarly work reported in this area. For example, Thiel & Semaru (2022) suggested that effectiveness of failure feedback – i.e. feedback indicating that one's performance does not meet expectations – may be a matter of personality of the recipient of such feedback. In similar vein, De Castella et al (2013) wrote on the categorization of students into a 2 x 2 matrix based on their combined fear of failure and orientation toward success. The design principles suggested in Table 1 also did not explore possible synergistic effects of mechanisms through students collectively in groups, or for that matter, faculty – especially in organizational context learnt from failure. As noted by Dahlin et al (2018) who studies the effect of opportunity, motivation and ability to learn from failure is a complex interplay between the different mechanisms, and establishing a causal relation is not always consistent.

Another possible limitation is that the design principles in Table 1, are more applicable for learning from failure from product innovation than for process safety in complex systems. Many are derived from studies in the business and/or organizational contexts and may need to be adapted for educational use. Some, such as *intelligent failure*, may not be appropriate for complex systems. Also as noted earlier, study of interventions in complex systems is an under-researched area. The entries in Table 1 are largely based on the first author's personal endeavors in the classroom. An area in Table 1, notably *Preparing the Mind* is derived from the first author's teaching experience. So is Autonomy-Supportive Teaching which is used by the first author in managing students learning in flipped classrooms (Cheah & Sale, 2019). *Sense-making* had its origin in the business context and adapted by the first author for study of interaction between different parts of chemical plant operations in the form of *Relationship between Process Variables* (Unknown Knowns) in Rumsfeld's Matrix (Cheah, 2023). The design principles outlined here should be contextualized to respective engineering domains, and an assessment must be made as to what the ultimate purpose of learning from failure is (e.g. innovation versus safety, etc).

Lastly, some of the design principles can be applied in more than one stage of the transformative process of Figure 2. In actual applications, several design principles may be incorporated and applied simultaneously within the same learning interventions. Along the same line of argument of Dahlin et al (2018), we posit that in actual applications, we can expect complex interactions among the different mechanisms from different design principles.

However, that does not mean that the classification as shown in Table 1 is of no value. As noted by Edmondson (2023), the goal of a framework is simply to help us think differently, so we can take thoughtful action; and not to provide or insist on rigid classification (p.293).

Possible Future Works

Velikova et al (2018), in the study of accidents in the construction industry, noted that there is a general disagreement in the field of what constitutes failure. The authors suggested that developing a taxonomy can allow development of understanding of underlying definitions and links behind failure, hence leading to more effective communication about failure; and improving learning from failure. We believe that our approach can benefit from developing our own taxonomy of failure for more-generalized applications that are applicable for various investigations into failure between the 2 spectrums from product innovation to process safety. A preliminary idea is to base the taxonomy of failure on the 4 stages of conceiving, designing, implementing, and operating a product, process, system or service.

Another area that warrants further development work is the SP-CDIO Syllabus. The parts that are relevant to learning from failure are shown in Appendix 1. From our preliminary mapping (not included in this paper), there are outcomes that can be related to learning from failure, but the connections are not very explicit, and many need to be inferred from the generic statements in the syllabus. The authors do not advocate adding to the CDIO Syllabus. Instead, we opined that the use of taxonomy of failure may be more useful as this can provide more specific guidance on the type of learning outcomes expected.

This work may open up a range of studies to investigate, for examples: Which creative combinations of design principles work best for a given intervention scenario, with possible identification of task-specific characteristics that lend themselves to be more amenable to certain intervention? What is the role of context in influencing the choice of design principles or the learning outcomes?

How do cultural differences affect the reception of failure, or the willingness to develop a failure tolerant mindset? Early work conducted by the second author suggests that “failure” has a specific cultural meaning, and that this should be taken into account when developing deliberate learning from failure interventions.

Moreover, Willems et al (2024) and subsequent ongoing work shows that a range of interconnected interventions might be superior to one-off activities as changing students’ mindsets is a complex process that takes time.

In any case, given the complexity of the possible interactions involved, the test of hypothesis and design of experiments can be complicated. In this regard, some creative use of artificial intelligence may be useful to identify plausible correlations between e.g. failure tolerance and innovativeness. This is especially so because using Generative AI, with is low threshold of engagement, can allow for the experimentation of multiple iterations in a given learning activity. That is, if designed appropriately, it can lower barriers for failure, trial-and-error, etc. and even open up avenues for more personalized learning experiences (e.g. see Huang et al, 2024).

Lastly, an area that we had not covered is that of learning assessment, and the related challenge of transfer of learning. Dahlin et al (2018) noted that ability is the learning mechanism that is most difficult to investigate, and there is a large gap in understanding of how to improve such ability. Although there are case studies that conclude that learning is difficult, with many factors that are used to explain when learning will not occur, there are fewer studies that explain a better ability to learn from failure (Dahlin et al, 2018, p.268). Detailed discussions of transfer of learning are a huge topic in its own right and it is beyond the scope of this paper. There are various instruments that can be used in the investigation on learning from failure, beyond the somewhat dated Student Failure Tolerance Scale (Clifford, 1988). Examples include instrument to measure Higher Education Students’ Fear of Failure in Learning (Choi, 2020), and Performance Failure Appraisal Inventory (Conroy et al, 2002). De Castella et al (2013) provided in-depth discussion of the latter, along with other related measurements. Future work may involve evaluating these instruments to ascertain if we can administer several of them to calibrate students’ responses from various perspectives.

CONCLUSIONS

This work presents a holistic approach towards development of failure-tolerant mindset among students, using a pedagogy termed learning from deliberate failure, guided by the CDIO Framework. A model of progressive development towards failure-tolerant mindset over the duration of program of study is suggested; which is appropriate over a range of failure scenarios from that of product innovation to process safety. A wide-range of learning interventions based on design principles aimed at developing specific aspects of the failure-tolerant mindset is proposed. It is suggested that each program can use the model by adapting it to the program needs, using selected design principles matched to the intended learning needs. It is anticipated that a combination of design principles can be creatively combined in any intervention setting to maximize the impact. As this is an emerging area, a range of topics (not exhaustive) for future research is suggested.

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BIOGRAPHICAL INFORMATION

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APPENDIX 1. Selected SP-CDIO Syllabus Relevant for Outcomes of Learning from Failure: Part 2.4 Attitudes, Thought and Learning

Texts in bold italics are applicable to outcomes for learning from failure, although not showed strong matching. Some rephrasing or elaboration will be necessary.

2.4.1 Demonstrate Positive Attitude and Willingness to Make Decisions in Face of Uncertainty

Explain the meaning in a task assigned, e.g. using Intrinsic Motivation framework
Recognize the needs and opportunities for initiative, e.g. analyse the potential benefits, risks of an action or decision
Explain one's own belief about one's own abilities (i.e. growth mindset)
Respond proactively with appropriate action, e.g. make preliminary decisions based on–information available at hand

2.4.2 Demonstrate Perseverance, Sense of Urgency and Will to Deliver

Display self-confidence, courage, enthusiasm and determination to accomplish objectives
Demonstrate a sense of responsibility for outcomes
Work independently or in teams with diverse compositions
Demonstrate openness in receiving feedback, criticism and willingness to reflect and respond
Identify root cause(s) of failure, and apply lessons learnt from failures

2.4.5 Demonstrate Critical Thinking

Explain the purpose and statement of a problem or issue
Identify and explain constraints within the problem or issue
Question assumptions, norms, practices or opinions
Use a range of critical thinking skills (e.g. analysis, compare and contrast, inference and interpretation, evaluation)
Analyse supporting evidence, facts and information
Identify fallacies, contradictory perspectives and underlying assumptions
Reframe and take a range of different perspectives
Explain different points of view and theories
Develop logical arguments and propose solutions
Summarise conclusions and explain key implications

2.4.6 Demonstrate Self-Awareness, Self-Reflection, Metacognition and Knowledge Integration

Identify one's skills, interests, strengths and weaknesses
Identify the strategies to overcome important weaknesses
Identify factors that promote effective thinking, e.g. motivation, openness, risk-taking, exposure to varied knowledge bases and ideas, etc
Identify barriers to effective thinking, e.g. traits, disposition, limitation of working memory, perception, lack of information, etc
Explain the role of emotion and feelings and the impact on decision-making
Explain need for well-being in a complex and changing world
Demonstrate metacognition in monitoring and evaluating one's quality of thinking
Reflect on one's own values, perceptions, etc;
Assimilate new knowledge into existing knowledge
Demonstrate transfer of knowledge to new context and/or applications

2.4.7 Demonstrate Learning Agility, Engage in Lifelong Learning and Educating

Identify key aspects of the learning process
Appraise one's own learning needs, set learning goals*,*
Use a range of learning strategies and skills (e.g. goal setting, learning plans, managing information, receiving feedback, etc)
Evaluate competence attainment in terms of goal(s) set and effectiveness of strategies employed
Explain how emotions and beliefs affect learning
Demonstrate self-directed learning in a range of contexts
Explain motivation for lifelong learning e.g. curiosity, remain relevant, professional development, etc
Identify strategies and skills for lifelong learning
Enable learning in and from others, e.g. share best practices
Establish good relationships with mentors and mentees
Demonstrate willingness to use advances in technology to aid learning

INCULCATING SUSTAINABILITY MINDSETS IN STUDENTS FROM ARCHITECTURE EDUCATION THROUGH CDIO FRAMEWORK

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ABSTRACT

Integrating sustainability mindsets with the CDIO framework is crucial for advancing sustainable development of products, processes, systems, and services. Emphasising sustainability values and knowledge enhances responsible decision-making. A sustainability mindset fosters responsibility and ethical awareness for future professionals in architecture education. This study empirically investigated the integration of UNSDG 13 (Climate Action) through CDIO standards 3 and 7 in architecture education to develop sustainability mindsets among students with transformative learning activities for first-year architecture students at Singapore Polytechnic. The pilot study explored case studies of vernacular architecture and utilised transformative pedagogies such as debates and role-playing to engage students with ethical dilemmas. A thematic analysis of students' reflections revealed emerging themes of enhanced understanding of ethical conflicts, appreciation for sustainability complexities, and preparation for ethical advocacy in (their future) professional settings. The findings underscore the effectiveness of transformative pedagogical approaches in developing key competencies related to sustainability, including value thinking, systems thinking, and integrated problem solving, thereby equipping future architects to navigate complex challenges and contribute meaningfully to sustainable development. This study contributes to the limited research on implementing CDIO in non-engineering fields (such as architecture), evidencing its potential to cultivate sustainability mindsets as an intrinsic component of architectural design.

KEYWORDS

Key Competence for Sustainability, CDIO Syllabus, Architecture Education, Transformative Learning, Standards: 1, 2, 3, 4, 7.

INTRODUCTION

The Conceive, Design, Implement, and Operate (CDIO) outcome-based curriculum design/redesign framework, which focuses on project-based learning and real-world applications, is widely utilised predominately in engineering education to enhance curriculum design, teaching methods, and assessment strategies. Given that sustainable products, processes, systems, and service lifecycle development and deployment are integral tenants of CDIO, it is advocated that the development of key competencies for sustainability can also be inculcated with CDIO (Cheah et al., 2025).

Sustainability mindset, as values, knowledge, and attributes that enable individuals to approach challenges and decision-making processes focusing on sustainability principles (Rimanoczy, 2020), is increasingly essential for promoting environmentally conscious decision-making. By inculcating these sustainability mindsets, alternative paradigms can be nurtured, fostering a sustainability mindset among students (Rieh et al., 2017) towards innovative and sustainable design solutions. Fostering a sustainability mindset in architecture education is crucial for instilling a sense of responsibility and ethical awareness among future practitioners (Núñez-Andrés et al., 2022). To date, there is a lack of empirical studies on the impact of integrating CDIO standards with a focus on UNSDG (United Nations Sustainable Development Group). This paper will hence focus on UNSDG No.13 (Climate Action) with the CDIO framework to foster sustainability mindsets among architecture students.

Architecture education includes more than just teaching design; it encompasses a wide range of topics, including structure, environmental science, sociology, and the arts, and requires an extensive understanding of how various fields, such as sustainability design strategies and principles (El-Feki & Kenawy, 2018; Farinea & Demeur, 2023), intersection and interdependence (Ummihusna & Zairul, 2021). This study aimed to empirically explore the integration of UNSDG No.13 through CDIO framework in Singapore Polytechnic's (SP) Diploma in Architecture's (DARCH) Architecture Foundation course to develop sustainability mindsets for first-year students through transformative learning activities. The two research questions guiding this study were: ***RQ1*****:** How do first-year architecture students perceive ethical dilemmas related to sustainability development? And ***RQ2***: How do first-year architecture students perceive their preparedness for ethical advocacy in professional settings after participating in a tutorial discoursing sustainability development? Students' qualitative reflections facilitate the exploration of recurring themes to gauge whether this pilot has provided a stable foundation for the future development of their sustainability mindset. Additionally, this study adds to the growing body of research that empirically explores the impact of infusing CDIO into a non-engineering course with the critical intention of developing learners' sustainability mindset.

UNSDG NO.13 (CLIMATE ACTION) IN ARCHITECTURE EDUCATION

Despite the increasing importance and relevance of UNSDG No.13 (Climate Action) in architecture education (Akgün et al., 2023), attempts to articulate the integration of SDGs into architecture curriculum and pedagogical practice remain scarce and underexplored (Burton & Salama, 2023). Furthermore, El-Kholei et al. (2024) emphasise the need to embed sustainability development goals (SDGs) into architecture education, ensuring that students are evaluated on their ability to incorporate sustainability into their designs. One of the key tenets of UNSDG No.13 urges collectives and individuals to take action to combat the ongoing climate crisis and its impact, including a strong focus on reducing greenhouse gas emissions from human activities. Buildings contribute up to 19% of greenhouse gas emissions (Mohkam

et al., 2022) and 30 - 45% of global energy use (Zamorano, 2022). Specifically, energy consumed for heating and cooling in residential, commercial, and industrial buildings accounts for a significant portion (Moldovan & Chisăliţă, 2021). Although the energy efficiency of heating and cooling systems can be improved through innovative technologies, architects could arguably consider passive strategies adopted by traditional low-energy vernacular buildings to reduce their energy impact.

However, architecture education's obsession with building aesthetics (Till, 2009) has reduced the rightful focus on designing low-energy designs through passive techniques. Academia's role in instilling appropriate value systems can support the development of intrinsic *sustainability mindsets* through its curriculum and pedagogical approaches. Fostering a sustainability mindset in architecture education is vital for instilling a sense of responsibility and ethical awareness among future architects (Núñez-Andrés et al., 2022). Different approaches can be developed by instilling sustainability attitudes and encouraging a sustainability mindset among students (Rieh et al., 2017) , which are essential for creating innovative and sustainable design solutions for the future.

THEORIES AND FRAMEWORKS TOWARDS SUSTAINABILITY MINDSETS

The CDIO methodology has been regarded as beneficial for engineering disciplines in sustainable development, as it integrates sustainability principles with CDIO standards and syllabi (Daneykin et al., 2016; Konst et al., 2022; Rosén et al., 2021). Sustainable products, processes, systems, service development, and deployment are critical tenants of CDIO, which, in turn, potentially catalyses the promotion of *sustainability* ***mindsets*** and attitudes. Kassel et al. (2016) elaborated that sustainability mindset stems from a deep awareness of the ecosystem, social sensitivity, and introspection, resulting in behaviours that benefit the greater good. A sustainability mindset is driven by values, knowledge, and attributes that enable individuals to approach challenges and decision-making processes with a focus on sustainability principles (Rimanoczy, 2020). In our world of accelerated change, it is imperative to develop a sustainability mindset as a critical attribute (Cheah, 2021). This pilot crystalised Cheah et al.'s (2025) 'generic' framework to develop students' key competencies for sustainability and extended the works of Ho and Leong (2023) and Luong and Le (2016) by examining frameworks for implementing CDIO in architecture courses. Given the interdependence of architecture between multiple stakeholders, disciplines, climatic, theoretical, and technical considerations, this study contextualised three relevant sustainability mindset principles, namely, 1) ***Systems Perspective/Thinking*** and 2) ***Ecological Worldview*** advocated by Rimanoczy (2021) and Rimanoczy and Llamazares (2021) with 3) ***Collaborative and Innovative Action*** as pedagogical approaches endorsed by Hermes and Rimanoczy (2018) and Kassel et al. (2016).

Infusing Systems Thinking/Perspective in Architecture Education

Systems Thinking/Perspectives is a holistic approach to reality, centred on the relationships and interconnections between the components that constitute systems by emphasising their patterns, flows, and processes (Rimanoczy, 2021; Rimanoczy & Llamazares, 2021). A systems viewpoint considers the requirements and interests of these interconnected subsystems during research, strategy development, and decision-making (Hawken et al., 2013; Senge, 2008). The architect works with others, as their roles and responsibilities are embedded in a more extensive relational system between the complexity of architectural design and other allied and non-allied disciplines. A systems perspective aids the empathetic and defined stages of the architectural design process, while optimisation aids in reducing

complex issues to inform the ideation design process (Miranda & Miah, 2021). The cross-pollination of systems thinking/perspectives in the design process potentially yields benefits in shaping social, economic, and natural environments (Avsec & Jagiełło-Kowalczyk, 2021). Moreover, systems thinking facilitates an understanding of the interconnectedness of buildings, infrastructure, natural environments, and communities, and the varying sources and detriments of poorly designed buildings negatively impact energy consumption.

Infusing Ecological Worldview: Ecoliteracy in Architecture Education

The ecological worldview facet of inculcating a sustainability mindset engages environmental concerns in protecting and restoring resources, mobilities, and agilities in adapting to changing conditions from a global perspective (Goleman, 2010; Nattrass & Altomare, 1999). Knowledge gleaned in academics provides a context in which learners can use it as a lens to examine our life experiences and choices in shaping our ecological worldview (Kassel et al., 2016). The foundational principle of ecoliteracy was elucidated and introduced by Orr (1991) as a branch of literacy that focuses on establishing sustainable human communities by reconstructing educational systems. Architecture courses can develop ecoliteracy by teaching the principles of ecology and sustainable design. For instance, learners would be exposed to how sustainability can be traced back to the traditional, low-energy approach of vernacular architecture. These indigenous design principles can inform modern sustainability design. Passive cooling strategies, rather than active systems (e.g. air conditioning), are fundamental principles that reduce the operational energy consumption in buildings. Notions exploring the relationships and connectedness between sustainability issues/events/strategies within macro and micro contexts can be expounded and critiqued upon. As such, students can have greater opportunities to reflect on buildings' roles in the broader ecosystem sustainability movement by considering energy flows, material cycles, and human interactions.

Infusing Collaborative and Innovative Action in Architecture Education

With Systems Perspective/Thinking and Ecoliteracy in place, a collaborative and experiential pedagogical approach is advocated by Kassel et al. (2016) to facilitate the development of learners' sustainability mindset. Instilling mindsets and value systems as soft skills will be challenging to impart explicitly (Liow, 2021), and alternative models must be explored. Traditional/passive models of knowledge transfers whereby learners are conditioned to be fact-absorbers and regurgitate them during their summative assessments have not moved beyond the *cognitive* strategies into the realm of developing mindsets (Hermes & Rimanoczy, 2018). Architecture educators ought to explore collaborative pedagogies that promote cross-pollinative exploration and experimentation with sustainability design strategies, technologies, and spatial configurations that will foster cultures of continuous learning and mental/cognitive agility in the face of the imminent and evolving sustainability challenges. This collaborative approach can be facilitated through Interdisciplinary projects, workshops, and studio courses that unite students from diverse fields to foster a holistic understanding of sustainable design principles and applications.

FILLING THE GAP: TRANSFORMATIVE PEDAGOGIES IN ARCHITECTURE EDUCATION FOR SUSTAINABLE DEVELOPMENT

Sustainability is inherently connected to transformative learning, yet traditional top-down pedagogies often fail to foster the necessary critical engagement and innovation among students. Transformative pedagogies aim to develop a **reflective** knowledge base, an appreciation for multiple perspectives, and a sense of critical consciousness and **agency** while

promoting profound and significant changes in habitual patterns, enabling new ways to role enactment (Kark et al., 2016). Shifting away from the hierarchical top-down paradigms of education, transformative pedagogy involves collaboration, exploration, instructional constructivism, autonomy, **experiential learning**, and **reflection** to create meaning that can change students' learning approaches (Gal, 2023). The ubiquitous One-on-One design studio pedagogy often coerces students to emulate tutors' design preferences and value systems (Crowther, 2013; Flynn, 2022). This has led scholars to advocate for a re-evaluation of traditional educational models to promote transformative learning experiences (Salama, 2016; Salama, 2021). *Transformational pedagogy* in architecture bridges sustainability-related building sciences and creative design, improves knowledge transfer, and tackles educational and professional obstacles (Altomonte, 2009) that foster a more profound comprehension of ecological issues. Scholars (Bedford, 2022; Burton & Salama, 2023) equally stressed that design educators could capitalise on UNSDGs and infuse sustainability principles into the curriculum to foster critical thinking to change learners' habitual patterns. As contemporary scholars have advocated the potential of infusing transformative pedagogies into problem-based design studios (El-Kholei et al., 2024; Hendawy et al., 2024; Salama & Burton, 2022), this study bridges this gap by inculcating students' sustainability mindset through theoretical subjects/topics. Transformative learning was leveraged to integrate value thinking competence and intrapersonal worldview towards Sense Making to address complex ecological challenges effectively.

CDIO Standard 3 For Sustainability Mindset: Integrated Curriculum

CDIO Standard 3 emphasises the importance of an integrated curriculum (vertical and lateral linkages) amalgamating disciplinary knowledge with **personal** and **interpersonal skills** towards product, process, system, and service building. Interpersonal skills were commonly referred to as communication, teamwork, emotional intelligence, and conflict management competencies, are essential for success in the workplace and society (Cacciolatti et al., 2017; Korniienko & Barchi, 2023). Kiviniemi and Przybyla (2019) supported the notion of an 'integrated curriculum' that intertwines the transfer of disciplinary knowledge with the development of essential knowledge, skill and attitude competencies, of which the mapping of specific learning outcomes and building on learners' prior knowledge to various courses ensures greater multidisciplinary coherence (Bridgstock et al., 2019). As such, lessons that impart and strengthen learners with ethical decision-making skills and critical thinking can be delivered to identify broader relationships and interactions within sustainability. These skills and a broadened worldview of their prior knowledge are required for students to critically analyse and reflect on **ethical dilemmas** and **contradictions** in the context of sustainability principles. Aligning with the CDIO framework's focus on integrated collaborative learning experiences and active learning, educators can establish a conducive problem-solving platform for students to question their prior assumptions and biases towards emerging epistemologies.

CDIO Standard 7 For Sustainability Mindset: Integrated Learning Experiences

Educational frameworks must prioritise integrating sustainability principles to prepare future professionals for a changing world. Henceforth, it is imperative to systematically include sustainability attitudes into the learners' Integrated Learning Experiences with CDIO Standard 7. Lozano et al. (2017) suggest that successful integration is undermined by the inclusion of (and extension) sustainability competencies (technical knowledge) with instructional approaches that focus on fostering students' sustainability mindset. These integrative approaches emphasise the acquisition of disciplinary knowledge and personal and

interpersonal skills through comprehensive learning experiences that prepare students to address **real-world sustainability** challenges. Such trajectories echoed a study incorporating sustainability into an engineering course (Grimal et al., 2021). Grimal et al. (2021) advocated, amongst others, **collaboration**, problem-solving, and systems thinking as key drivers. Likewise, Tomasella et al. (2022) advocated the integration of the UNSDGs with *real-world experiential learning* (simulated workplace scenarios and case studies) to scaffold learners' understanding of sustainability issues and to develop a sustainability mindset. Such notions have led to the increasing importance of *collaborative* learning. Besides educational outcomes of improved teamwork abilities, communication and negotiation skills when engaged in a communal discourse of real-world challenges, such collective platforms potentially offer individuals and groups an understanding of their standpoints and contribute to socio-diversity, thus promoting sustainability practices (Andrade & Sorrentino, 2014). The progressive development of a sustainability mindset throughout the DARCH programme resonates with OBJ advocating the development of values thinking and intra and interpersonal competencies. This paper discoursed efforts in DARCH's first-year Architecture Foundation course's adaption of CDIO Standard 4, focusing on teamwork and communication to enhance intrapersonal competencies while introducing students to basic system thinking as essential for fostering a sustainability mindset.

PILOT: OPERATIONALISING CDIO STANDARDS IN SP'S ARCHITECTURE COURSE

The pilot, implemented within the DARCH Programme at SP, highlighted the urgency of instilling sustainability values by fostering investigative approaches in students' creative design processes, aligning with the contemporary *zeitgeist*. Architecture education is a multidimensional field that discourses and incorporates philosophy, technology, and social consciousness in students' design projects, to which sustainability, energy efficiency, and environmental design principles are increasingly pertinent (Ceylan et al., 2021; Gucyeter, 2016). While imparting technical skill sets and techniques to infuse environmental, social and economic sustainability in student projects was the primary modus operandi in architecture education, pedagogical strategies towards inculcating sustainability mindsets were often overlooked. Such assertions were advocated by Sotnikova et al. (2019), who argued that a comprehensive teaching and learning approach must integrate sustainability as an intrinsic value embedded in theoretical courses and design studios to deepen students' knowledge and adaptation of sustainability mindsets (Dhaouadi & Leclercq, 2022). Additionally, instilling sustainability mindsets aligns with SP's goal of fostering ethical and responsible citizens. This pilot study explored the development of baseline sustainability competencies in values thinking, guided by the framework in Figure 1.

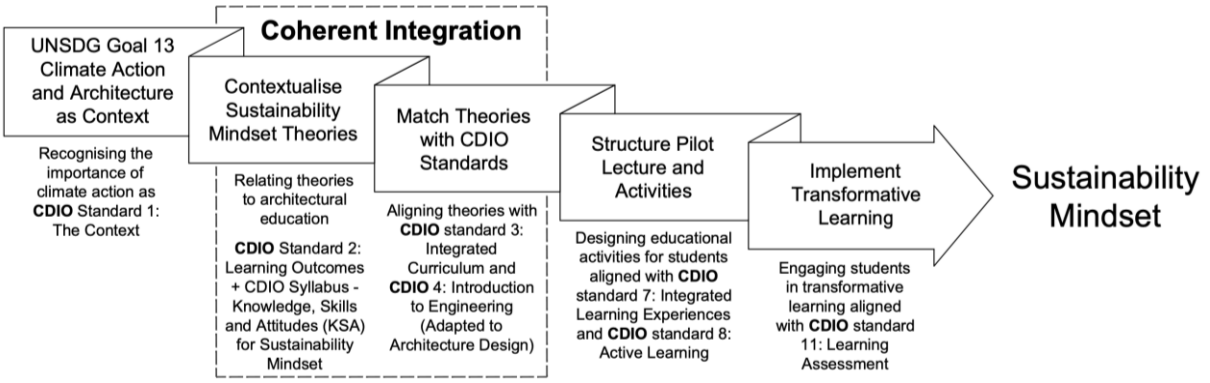


Figure 1. Relational Diagram and Conceptual Framework of the Pilot Study

CONSTRUCTIVE ALIGNMENT IN PILOT DESIGN: INTEGRATING SUSTAINABILITY AND ETHICAL COMPETENCIES IN ARCHITECTURAL EDUCATION

In the design of the two pilot activities, constructive alignment was used as guidance, ensuring that the course's learning objectives, instructional methodologies, and assessment tactics were coherent to support student learning effectively (Biggs, 1996). The lecture was conceived to rest on the foundations of prior lessons, focusing on a critique of contemporary sustainability issues and contradictions. The lecture had explicit links to adjacent DARCH courses whereby the passive approach in architecture design and its impact on thermal comfort and design strategies were expounded. Figure 2 illustrates the interplay between the elements of the pilot study's ***constructive alignment*** **with the CDIO syllabus** and **standards.**

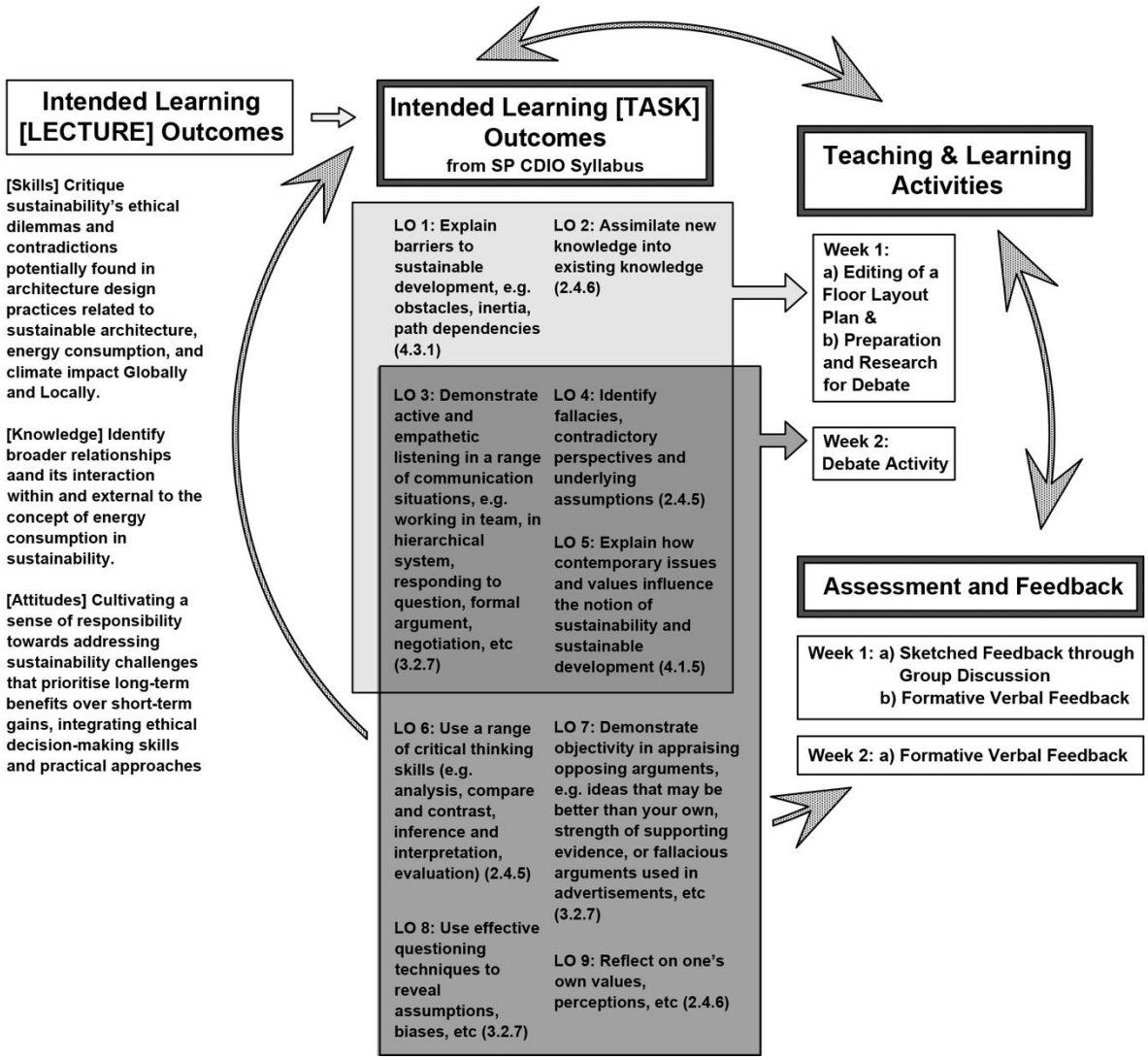


Figure 2. Relational mapping of the learning activities' Constructive Alignment framework with the SP CDIO syllabus and standards for the pilot.

The pilot lecture's **learning outcomes** explored notions of systems thinking to unveil the interconnectedness of buildings, stakeholders, and their natural environments concerning the energy consumption of buildings. Ecoliteracy is developed by teaching principles of ecology and low-energy sustainability design strategies and presenting real-world scenarios. Students can then reflect upon and analyse ethical dilemmas, enhance their ethical awareness and decision-making skills, practice identifying ethical issues and conflicts through case examples,

and prepare for ethical advocacy in organisational settings (Dodd & Jansson, 2004). Similar to the real-world scenarios discussed in the lecture, two tutorial activities (CDIO Integrated Learning Experiences) were designed as illustrated in Figure 3. Learners engaged in activities that exercise their agencies with ethical dilemmas and contradictions related to professional practices, focusing on building their **personal** and **interpersonal skills** and activating their awareness/competencies, systems thinking competencies, and practical experiences that equip them to make informed decisions that promote sustainability (Stewart et al., 2021). The discussion about real-world dilemmas stresses the importance of ethical practices in governing a person's behaviour or decisions in professional practice, ensuring that individuals prioritise long-term advantages over short-term gains (Biedenweg et al., 2013) will be explored in the next section.

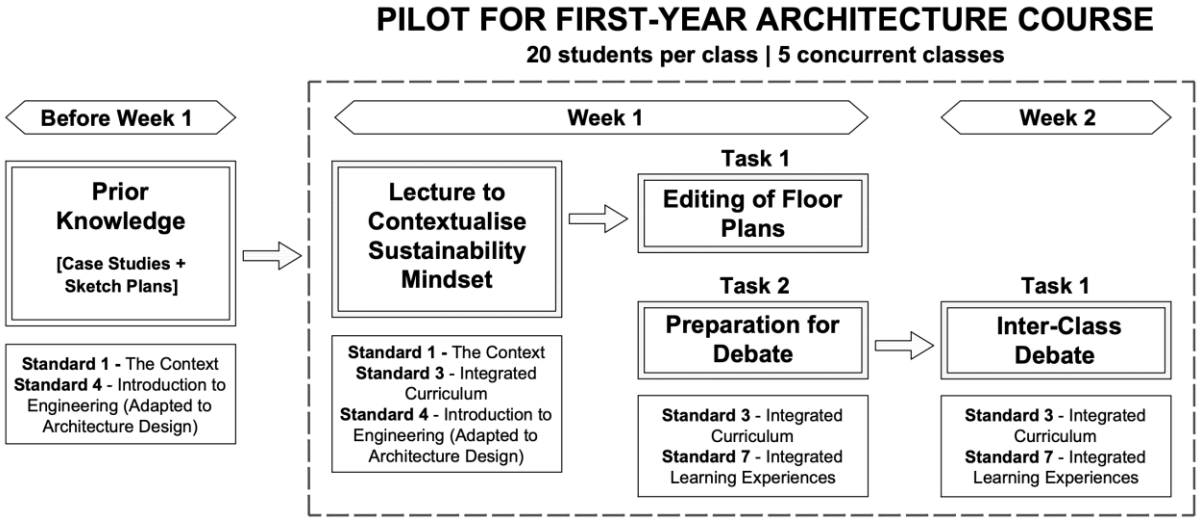


Figure 3. Transformative Learning activities and relations to CDIO standards

Integrating Real-World Scenarios: Floor Plan Redesign and Debate Activities in Architecture Education

The two learning activities spanned two weeks (Figure 3) and aimed to facilitate students' attainment of key competencies of sustainability, such as value thinking, systems thinking and integrated problem-solving. Activity 1 involved editing an apartment's floor plan, while Activity 2 grouped students for a debate. Architecture practices often face pressure from clients, leading to design compromises. **Activity 1** mirrored a real-life scenario where a client requested the master bedroom face the western landscape as a development 'selling point'. Although this offers desirable views, it exposes the room to intense western sunlight, increasing energy consumption due to air conditioning. Students must first identify the floor plan's shortcomings and comply with the client's demand for an unblocked western view with proposed sketches to reduce the building's cooling loads by reconfiguring the spatial layout.

As referenced in Figure 3, students were expected to be engaged in a debate in **Activity 2.** Debate-based pedagogy in higher education potentially enhances students' classroom engagement, critical problem-solving skills, perspective-taking skills, empathy, and advocacy skills (Mabrey et al., 2021). While allowing a discourse of competing and multiple perspectives, the debated framework of dilemmas, which requires solutions and one-sided choices, to a framework of paradoxes that embraces tensions and contradictions can contribute to meaningful, transformational learning (Kark et al., 2016). Debates theoretically empower learners to become active citizens beyond the classroom, preparing them for future societal

engagement (Thomas, 2011) with the crystallisation of value systems through mindset development via interactive educational interactions (McInnes, 2013). Echoing Hermes & Rimanoczy's (2018) assertion that the contentious debated topic creates fluid boundaries between what may be considered 'right' and 'wrong' hypothetically establishes a supportive learning atmosphere conducive to instilling a sustainability mindset.

Students were grouped into three groups (for, against, and the jury) for Role Play Debating activity. Typically, clients urge architects to choose cost-effective finishes to meet budget constraints. The architect was tasked with selecting a marble finish for a new 50-storey office tower's lift lobby in downtown Singapore. Two samples were shortlisted with the understanding that successful project execution might lead to future opportunities. However, the architect's firm is financially strained, with no new projects expected, and the architect is apprehensive about potential conflicts with the cost-focused client's Project Manager. In preparing for a presentation, the architect evaluates Sample A from Country X at $35 per square foot with nine hours of transport time and Sample B from Country Y at $65 per square foot with a 1.5-hour transport time. Both samples are similar in size, thickness, durability, maintenance, and appearance. The architect must decide which tile sample to propose.

DATA COLLECTION AND ANALYSIS METHODOLOGY

To answer ***RQ1*** and ***RQ2***, students were invited to deposit their reflections via an online portal with these reflective questions. To answer ***RQ1***, students will reflect upon, *'How has the tutorial on* sustainability *architecture and energy enhanced your understanding of ethical dilemmas and conflicts in the context of sustainable architecture?'* and aligned to ***RQ2****, 'How has the tutorial prepared you for ethical advocacy in professional settings?' a*fter the lecture and second learning activity. The survey was administered to 5 studios of 20-21 students each and 130 responses were collected from both occasions via Microsoft Forms. Personal data were not collected as the option "*Anyone can respond – Anonymous response, doesn't require sign-in*" was selected to ensure their anonymity. This study was approved by Singapore Polytechnic's Institutional Review Board with protocol number: 202407-01. The dataset was analysed using the Atlas.Ti qualitative analysis software. After thoroughly reviewing the data, the 'Intentional AI Coding' function identified relevant codes related to specific concepts based on the research questions, which were validated and refined. These codes were then manually grouped and regrouped into themes by identifying patterns and trends (Braun & Clarke, 2006), and recurrent themes were reviewed to ensure accurate data representation supported by participant quotes.

However, it is important to acknowledge a few limitations of this research design and methodology. As this pilot assessed learners' sustainability mindsets shortly after the implementation of the activity, this short-term assessment only provides us with a potential glimpse of sustainability mindset in their future advocacies and not their long-term effects. With this projects' extension into the upper years of the DARCH programme, longitudinal studies will be carried out for a better understanding on how students' sustainability mindsets evolve over time. While students' qualitative data provides rich insights, that are inherently subjective and may be influenced by individual biases and confounding variables. These variables may include personal values, or external influences (e.g., family background, media exposure), may complicate efforts to isolate the impact of the educational interventions.

DISCUSSION

Two main themes were identified for each RQ. Notions of **Ethical Dilemmas** and **Enhanced Understanding** were themes related to ***RQ1***. **Preparation for Future Practices** and **Appreciation of Sustainability** were themes identified in ***RQ2***.

Deeper Appreciation and Enhanced Understanding of Ethical Dilemmas

Despite lacking formal experience in architectural design, students anticipated future conflicts between aesthetics, function, and sustainability through ***Systems Perspective/Thinking***, highlighting how elements interact and foreseeing ethical dilemmas, as illustrated in the theme of **Ethical Dilemmas** for ***RQ1***. One participant stressed: "*(The activities) enhanced my understanding of the ethical dilemmas in architecture. It showed the conflict between aesthetic goals and energy efficiency, as well as the challenge of balancing costs with sustainability*" and "*(the activities) let me understand how easy it is to pretend that the building is sustainable when it really isn't"*. As architectural practices are not solely aesthetically driven (El-Feki & Kenawy, 2018; Farinea & Demeur, 2023), the authors argue that these early exposures to the independent relationships of systems thinking have the potential to facilitate their transition into responsible designers. Such necessities were similarly argued by Kurjenoja et al. (2021), whereby the importance of developing design competencies sensitive to reality was considered paramount to develop, and O'Dwyer and Gwilliam (2019) advocated the need for architecture education to impart civic responsibilities to students and encourage them to consider social principles in their professional practices.

Value systems, soft skills, and mindsets can be challenging to impart through lectures and activities (Liow, 2021), as sound decisions must be made considering the situational context. Such assertions have complimented the second theme: ***Enhanced Understanding***. This study explored group 'debates' to foster collaboration, critical thinking, and diverse perspective evaluation through ***Collaborative and Innovative Actions.*** One learner reflected: "*Especially after the debate session, there are still no right answers on how to solve sustainability issues and the practical/ethical balance in the decision we make as an architect*", mirrored the debates as a pedagogical tool in addressing complex issues and shaping students' understanding of public policy, ethics, and social values. Debates stimulate critical thinking and reasoned argumentation, thus creating lasting educational memories (Palatty et al., 2018). Another learner reflected: "*(the activities) allowed me to realise that there are pros and cons to each architectural approach. It is also important to take risks for the greater good sometimes"*, reinforcing that students' enhanced understanding of these complex issues facilitates their development of a well-rounded and conscientious approach to design, preparing them for its complexities and agencies. This discursive/argumentative approach was echoed in Cheah's (2021) study, which advocated 'sustainability as a discourse'. Seatter and Ceulemans (2017) clarified that by exploring sustainability as a collective discourse, emerging epistemologies can be derived through debates and disagreements among different viewpoints rather than subscribing to the widely accepted absolute beliefs and practices of sustainability. Furthermore, scholars (Balachandra, 2019; Sibanda & Naidoo, 2023) advocated the promotion of desired attitudes, mindsets, and behaviours through experiential learning.

Preparedness and Appreciation of Ethical Advocacy

Regarding students' reflections on their ethical advocacy in professional settings for ***RQ2***, two main themes emerged as: **Preparation for Future Practices** and **Appreciation of Sustainability**. Highlighting the interplay among stakeholders' objectives and the need for effective communication underscores a ***Systems Perspective/Thinking*** as Preparation for

Future Practices. One participant remarked after the debate activity: "*I think the important thing is to discuss with both parties (clients with architects) to obtain a desirable outcome" and "(the activities) have prepared me to professionally prepare myself for future conflicts and dilemmas in the industry, as well as how to advocate for my ideas to my clients".* The intersection of architecture and sustainability involves a nuanced interplay between ethical considerations and practical decision-making. Such conundrums were argued to be ubiquitous in professional practices, whereby clients' objectives (aesthetics & budget) may not echo architects' environmental considerations. Angral (2019) similarly suggested that clients often prioritise aesthetics and cost over adjacent pertinent issues, such as environmental considerations, leading to potential conflicts between the architect's vision and the client's expectations. Dansoh and Frimpong (2016) emphasised that ineffective communication and understanding of each party's priorities might lead to misunderstandings and discontent. The architect's job extends beyond design; it includes educating clients on the long-term advantages of sustainability, which may necessitate initial investments that coincide with aesthetic goals. Preparing students for these imminent polemical conflicts in academia can prepare them for future ethical advocacy in their careers.

Participants reflected on the **Appreciation of Sustainability** as extensions of students' ***Ecological Worldview***. Students' thoughts reflected a deeper understanding of sustainability that broadens their ecological perspective beyond superficial concept that fosters the integration of sustainability as a core element. "*It made me understand that sustainability is just a term used to greenwash us, and we should rather use responsibility as we should be taking care of our planet",* as one student reflected. Both the lecture and activities helped in catalysing of transformative learning moments as students realised that sustainability design practices must shift beyond the imagery hypes and trends in mainstream perceptions of sustainable development. Sustainable development must be regarded as a strategic framework in architectural practice, rather than a transient trend (Grover et al., 2018). This shift into critically analysing a piece of architecture designed with sustainability principles in mind is argued to be essential in their education. As one participant reflected: "*It made me rethink about what other design choices can be considered when trying to be "sustainable*", this shift in viewpoint allows students to think of sustainability as an intrinsic component of the design process, rather than an afterthought or a superficial addition (for the sake of needing to have a sustainable design). Exposing architecture students to complex conflicts prepares them to navigate ethical challenges and advocate for sustainability solutions in their careers.

Extension of Prior CDIO studies and Future Research

This study explored in detail on how CDIO standards can be infused into the pedagogies of architecture education by adopting an interpretivist take of students' sentiments and reflections, extending the paucity body of studies expounding on the macro application of CDIO standards in architecture education. While Ho and Leong (2023) discoursed the macro framework for operationalising CDIO standards to guide program managers, our research contributes to this trajectory by focusing on the micro aspects of pedagogy, specifically emphasising the development of a sustainability mindset. The study's pedagogical approach can also be contextualised as an extension of a study by Reidar et al. (2023) whereby CDIO standards were used to enhance collaborative and contextual learning environments of architecture education. Likewise, the frameworks discussed in this study also compliments Luong & Le's (2016) article of which the authors explored relevant problem design methodologies in architecture design that align with current and future real-world trends.

CONCLUSION

As climate emergency persists, continued pedagogical efforts to embed sustainable development goals into architectural curricula and pedagogies through CDIO standards to shape future practitioners to effectively address complex sustainability challenges in the built environment will be increasingly paramount. This study emphasises the critical role of integrating the CDIO Framework with UNSDG No.13 in architecture education operationalising Cheah et al.'s (2025) 'generic' framework to foster sustainability mindsets among students.

To achieve this, this research emphasises on transformative learning activities (debates and role-playing) which engage students in ethical dilemmas related to sustainability. This pedagogical approach encourages critical thinking and reflection, allowing students to navigate complex sustainability challenges. By fostering a deeper understanding of ethical conflicts and the complexities of sustainability, the study moves beyond traditional rote learning methods, promoting a more engaged and thoughtful learning experience.

Building on the insights of this study, which echoed key notions of Systems Perspective/Thinking, Ecological Worldview, and Collaborative and Innovative Action, future longitudinal studies will allow researchers to track changes in students' sustainability mindsets over time to enhance our understanding and attitudes towards sustainability evolve as they progress through the curriculum. Similarly, by utilizing an explanatory sequential mixed methods design can provide a more comprehensive understanding of students' sustainability mindsets. With a longitudinal framework, the quantitative measurements of sustainability mindset could quantify changes in time, while focus groups can offer deeper insights into students' experiences and reflections on their learning. This triangulation of data can strengthen the validity of the findings. Alternative models of transformative learning would be experimented supporting the development of learners' key competencies of/for sustainability. This project is currently in the stages of extending laterally within the first DARCH courses and vertically into the second-year studios for greater coherence and continuity.

The qualitative analysis of student reflections revealed a deeper understanding of the complex interplay between aesthetics, functionality, and sustainability in design. Furthermore, students expressed greater preparedness for ethical advocacy in their professional futures, highlighting the necessity of effective communication with clients regarding sustainability issues. Ultimately, the findings illustrate that transformative pedagogical approaches can effectively cultivate baseline key sustainability competencies, value thinking, systems thinking and integrated problem-solving, equipping future architects to navigate the multifaceted challenges and contribute to sustainable development.

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CDIO PEER-TO-PEER SUPPORT ON EDUCATION FOR SUSTAINABLE DEVELOPMENT: EXPERIENCE FROM PILOT RUN

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ABSTRACT

This paper documents the CDIO peer-to-peer support (P2PS) experience between 2 peers, that is Singapore Polytechnic (SP) and Batangas State University (BatStateU). First, the CDIO P2PS initiative is introduced along with an overview of the previous work that laid the ground work for this P2PS experience. This foundational work enabled both institutions to enhance education for sustainable development through sharing of expertise. Then, the paper provides a brief comparison between CDIO P2PS and existing learning communities. CDIO P2PS stands out due to its unique structure, specifically, it involves two educational institutions that are committed to learning from each other's educational practices and aligned with the CDIO Framework which further promotes ongoing and future collaboration. The paper also elaborates on the learning points gathered from the participants at both SP and BatStateU. These insights highlight the positive outcomes and benefits experienced by both institutions as a result of this P2PS. The open-mindedness and responsiveness of both peers played a significant role in the overall success. In conclusion, this CDIO P2PS experience is deemed a resounding success for this collaboration not only enhances the educational practices at both institutions but also sets a precedent for future peer-to-peer support initiatives.

KEYWORDS

Peer-to-Peer, Chemical Engineering, Sustainable Development, CDIO Standards 9, 10, 12

INTRODUCTION: WHAT IS THE CDIO PEER-TO-PEER SUPPORT (PSP2)

The basic idea of the Peer-to-Peer Support (P2PS) process is to benefit participating programs from CDIO members by allowing them to share practices and enhance their programs continuously by having critical friends working for their program, so as to gain deeper learning from the experiences of their peers. For the CDIO community, the activity builds up a history of evidence about the positive impact of CDIO on the quality of engineering education and its graduates. It makes it possible to identify regional or global trends that give guidance to the advancement of the CDIO Initiative. Engaging in the P2PS will make the CDIO network more active and collaborative, delivering a whole new and interesting experience to experienced CDIO members, and becoming more attractive to new and potential members. In short, the P2PS activity provides one's program the opportunity to share good practices with one's peer and at the same time learn from the peer.

This paper shares the experience of two institutions – Singapore Polytechnic (SP) from Singapore and Batangas State University (BatStateU) from the Philippines – on their experiences in the pilot run of the P2PS, focusing on the coverage of sustainable development in the curriculum, for the chemical engineering discipline.

LITERATURE REVIEW

The section is divided into 3 parts. The first part traces the history of the P2PS, initially known as Peer-to-Peer Review Process. The second part provides a brief discussion on how the CDIO P2PS resembles and/or differs from other peer support mechanisms, namely Teacher Support Group (TSG), Community of Practice (COP) and Faculty Learning Community (FLC). The third and last part explains the existing efforts by the two institutions in enhancing education for sustainable development (ESD) that sets the context for the P2PS.

A Short History of the Peer-to-Peer Support

The value of membership to the CDIO community of practice lies in the meaningful interrelations and exchanges between members. This usually takes place at international CDIO conferences and regional meetings. However, there are limitations on how much can be achieved within the short duration of such conferences and meetings. As a global community there is a broad desire to introduce other opportunities for members to interact with one another beyond the conferences and regional meetings, to stimulate members to share practices in teaching and learning using the CDIO Framework, so as to continually improve their education programs.

The idea for a peer-to-peer review, was borne out from earlier efforts of key members of the European CDIO Members to enhance the quality of their educational offerings (see for example, Clark, et al, 2016; Kontio, et al, 2006). Then CDIO Co-Director (2017-2022), Aldert Kamp stressed the point that CDIO needs to demonstrate its usefulness in terms of evidence for its positive impact, in order to continue to attract new members (Kamp, 2021). One of the recommendations he made was:

> "Recommendation 3: Develop and implement a cyclic peer-to-peer evaluation process by and for the members to build up a history of evidence on local and global level, and stimulate the members to share practices and improve continuously."

The outcome, at the highest aggregate level of the CDIO Initiative, is that the gathered information from these peer support should be used to build a history of evidence on the impact

of CDIO on the quality of engineering education and its graduates. It would also enable the identification of regional and global trends that give guidance to the advancement of the CDIO Initiative (Kontio, Leong & Cheah, 2022).

A virtual roundtable event was held at the 2021 International CDIO Conference hosted in Bangkok, Thailand to identify the challenges facing CDIO that need to be addressed, which fall under the following two areas (Junaid, et al, 2021a):

(1) To establish a cyclic peer-to-peer review for CDIO members that is fit-for-purpose.

(2) To set up a research framework that can be used to build a history of evidence and impact of CDIO in practice.

The output from the 2021 virtual roundtable are three-folds:

(1) Propose a structured guideline for a peer-to-peer support cycle for approval at CDIO Council

(2) Develop set of tools using current self-evaluation, standards and simplified version of Quality Assurance and Enhancement Marketplace (QAEMP)

(3) Propose a buddy system for pairing members (consider diverse team pairing and visits as a highly recommended action)

These ideas were further deliberated at another virtual roundtable, conducted using a “Chase-the-Sun” format in three successive sessions across three time zones at the November 2021 International Working Meeting, hosted in Trondheim, Norway where lessons learnt from earlier efforts where also shared (Junaid, et al, 2021b)

After the works from two working groups in 2022 – one at the 2022 International CDIO Conference hosted on-site in Reykjavik, Iceland (Kontio, Leong & Cheah, 2022); and another at the 2022 International Working Meeting hosted in Turku, Finland (Kontio, 2022) – the final form of the P2PS emerged. These include the structured approach to P2PS, design of various templates for use, ranging from initial registration of interest, to planning a visitation, capturing key discussion points, and conclude with a report to CDIO Council.

As this time, SP had embarked on integrating sustainable development at the institutional level (Cheah, Lim & Chao, 2022). SP in its capacity as the Co-Leader for the CDIO Asia Region, embraced the P2PS initiative and operationalized it as illustrated in Figure 1. The P2PS was shared with the Asian members to look for suitable partner(s). SP added P2PS into its CDIO portal at https://sp-cdio-centreforteaching.sp.edu.sg/. SP also participated actively in promoting the P2PS, in the workshop that was held the 2023 International CDIO Conference hosted on-site in Trondheim, Norway (Kontio, et al, 2023) and conducted a roundtable at the 2024 International CDIO Conference hosted on-site in Tunis, Tunisia.

In 2022, SP and BatStateU came together to pilot the P2PS with the intention of exchanging learnings about ESD implemented in each institution. The process and experience from this pilot run of PSP2 is elaborated in later section.

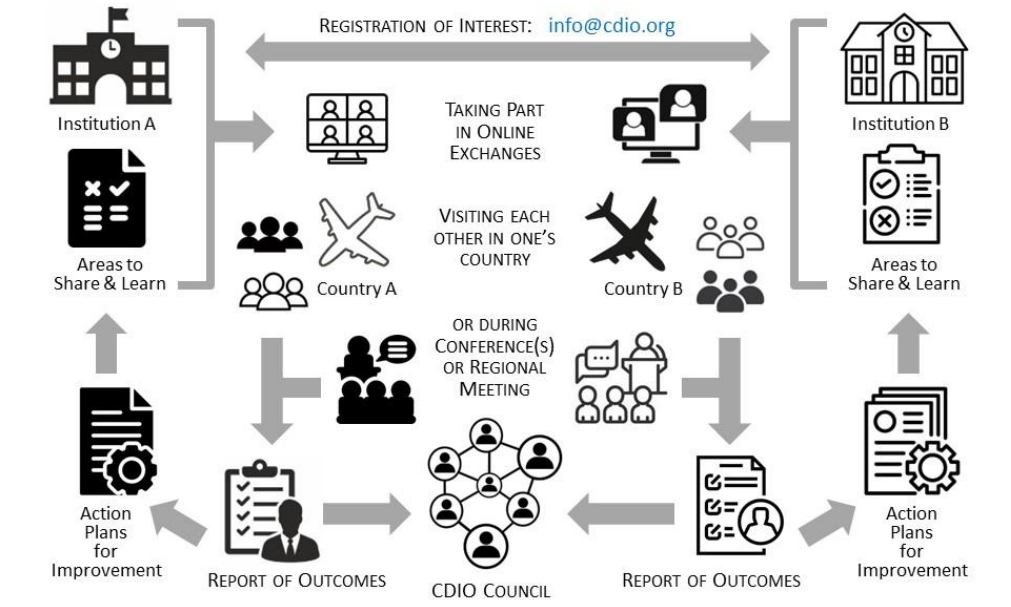


Figure 1. CDIO Peer-to-Peer Support - How It Works

Peer-to-Peer Support vs. Teacher Support Group vs. Faculty Learning Community

According to Riessman (1989), peer support as broadly defined, refers to a process through which people share common experiences or face similar challenges come together as equals to give and receive help based on the knowledge that comes through shared experience (Penney, 2018). Sometimes referred to as self-help or mutual aid, peer support has been used by people dealing with different types of social circumstances, emotional challenges, and health issues, including those with alcohol or drug problems, bereaved individuals, and people living with physical illnesses or impairments (Penney, Mead & Prescott, 2008).

Peer support group in the context of education, is often referred to as Teacher Support Group (TSG), which Lieberman & Grolnick (1998) note as playing a major role in "providing opportunities for teachers to validate both teacher knowledge and teacher inquiry". Richards & Farrell (2005) define a teacher support group as "two or more teachers collaborating to achieve either their individual or shared goals or both on the assumption that working with a group is usually more effective than working on one's own". Typically, a support group will involve a group of teachers meeting to discuss goals, concerns, problems, and experiences. The group provides a safe place where teachers can take part in such activities as collaborating on curriculum and materials development, and review, plan, and carry out activities such as peer coaching, team teaching, action research, and classroom observation.

In higher education, the term learning community has many meanings. Any kind of learning community seeks to bring together a small group of peers who share common interests in order to learn together, support and encourage each other (Cox, 2004). Faculty Learning Community (FLC) is defined as a cross-disciplinary faculty and staff group of six to fifteen members (eight to twelve members is the recommended size) who engage in an active, collaborative, year-long program with a curriculum about enhancing teaching and learning and with frequent seminars and activities that provide learning, development, the scholarship of teaching, and community building. FLCs are also closely related to the concept of "community of practice (COP)", which is most closely associated with the work of Etienne Wenger (1998).

In a COP, people come together to talk about common interests, concerns, problems, and ideas. Learning is a social phenomenon, not merely an individualistic one. Participation in a community of practice results in shared meaning and a collective identity.

Table 1 below provides a comparison between the 4 types of approaches whereby faculty can work with one another to improve their teaching and learning. (Full disclosure – entries in columns for TSG, FLC and COP were generated using Microsoft Copilot generative AI tool).

Table 1. Comparisons Between Teacher Support Group, Faculty Learning Community, Community of Practice and CDIO Peer-to-Peer Support

Criteria	TSG	FLC	COP	CDIO-P2PS
Definition	A group of teachers or school leaders who engage in reflective circles to explore and reflect on challenging classroom and school experiences.	A peer-led group of faculty members who engage in an active, collaborative, year-long program, structured to provide encouragement, support, and reflection.	A group of people who share a common concern, a set of problems, or an interest in a topic and who come together to fulfil both individual and group goals.	A group of educators with common interest in sharing practices in using the CDIO Framework to address teaching and learning issues.
Size	Typically, 4-6 members.	Typically, 6-12 members.	No size limitation.	No size limitation
Focus	Focuses on reflective practice and mutual support.	Focuses on multi-disciplinary collaboration, scholarly teaching, and the scholarship of teaching and learning.	Focuses on sharing best practices and creating new knowledge to advance a domain of professional practice.	Focuses on sharing practices and creating new knowledge in alignment to the CDIO Framework
Practice	Must put into immediate practice what has been learned.	Encourages the application of learned concepts in teaching.	No obligation to put new knowledge into practice.	New knowledge enhances current practices and promote member collaboration
Membership	Comprises teachers or school leaders.	Comprises faculty members from various disciplines.	Can include anyone with a shared interest in a particular domain.	Can include anyone with a shared interest in CDIO and those already in the CDIO community

As can be seen, the 4 approaches have similarities, all sharing the common goal of knowledge exchange and collaborative learning. However, the CDIO P2PS is distinct that it involves two educational institutions, eager to learn from each other's educational practices. This typically occurs when one institution has more advancement in certain aspects of CDIO implementation and the other institution seeks to understand how the CDIO implementation was carried out and the factors that contributed to its success. New knowledge is created to advance understanding with alignment to the CDIO Framework and promote further collaboration. Participation as of now lies within the CDIO community.

Existing Effort in Enhancing Education for Sustainable Development at SP and BatStateU

At SP, the ESD is implemented through the Common Core Curriculum (CCC) which aims to develop baseline emerging digital and human skills in students. These skills are integrated to the diploma programs so that they can be deepened or applied in the domain modules (Cheah, Lim & Chao, 2022). Since AY2022/2023, the CCC is integrated into the Diploma in Chemical Engineering (SP-DCHE) program using a spiral curriculum model (Oh, et al, 2024) by pairing CCC modules with domain modules while sustainable processes are used in the engineering workspaces that supports the teaching and learning of the curriculum.

At BatStateU, the Bachelor of Science in Chemical Engineering program (BatStateU-BSChE) offers a rigorous academic program to produce chemical engineers who achieve professional growth through the practice of chemical engineering and adhere to professional, moral and ethical standards within the profession. The program also offers a variety of research works with direct impact to the community where students and faculty members are actively involved. These research works require students to solve real community issues using existing technology and resources that lead to sustainable solutions. Additionally, the expertise and dedication of the faculty members teaching the BS Chemical Engineering program are evident. A number of faculty members who are affiliated with the chemical industry enhance the program's practical relevance and industry connections.

While both institutions offer chemical engineering programs at different levels, one at degree level (BatStateU-BSChE) and the other at diploma level (SP-DCHE), the context of learning are vastly different due to the location, availability of resources, culture and beliefs of the community. Though the sharing depends on each institution’s experience and expertise, in this pilot run, these differences enabled the rich sharing between both institutions.

EXPERIENCE FROM PILOT RUN OF P2PS BETWEEN SP AND BATSTATEU

The peer support between SP-DCHE and BatStateU-BSChE began in 2022 through a series of virtual meetings designed to familiarise each institution with the other’s curriculum, the implementation of CDIO in the curriculum and sharing work related to CDIO. As P2PS is new to both SP-DCHE and BatStateU-BSChE, a short workshop was conducted for SP faculty members to explain the concept of P2PS and use CDIO to integrate sustainable development as the context. Likewise, a short online briefing for BatStateU faculty members was held.

Two documents are required to be submitted to the CDIO Council as records – namely the “Registration of Interest” and “Peer-to-Peer Support Report” (as shown in Appendix 1). Several other forms were also recommended to assist with the planning and implementation of the P2PS. In addition, SP introduced additional forms to help monitor subsequent exchanges between the parties.

A shared folder hosted by SP was created for both institutions to share documents of best practices which can be used as reference. The CDIO P2PS forms a continual conversation for both SP-DCHE and BatStateU-BSChE and this was strengthened when SP made a physical visit to BatStateU in October 2023.

In preparation for the physical meet-up in October 2023, both SP-DCHE and BatStateU-BSChE carried out a self-evaluation on good practices that each institution would like to share with others and things that each institution would like to learn from peers within the CDIO

standards. This self-evaluation was documented in a "Registration of Interest" form and both institutions referred to this information and made the necessary preparation for the meet-up.

Faculty members from SP comprised of four engineering disciplines, namely Built Environment, Chemical, Electrical and Mechanical Engineering, was hosted by faculty members from BatStateU on October 5 to 7, 2023. In addition to the participation of faculty members from BatStateU as illustrated in Figure 2, faculty members from the BatStateU Centre for Sustainable Development and Centre for Innovation in Engineering Education also took part in this 3-day meeting.

The first two days of the meet-up were dedicated to discussions and facility visits, whereby each discipline held its own meetings for deeper engagement. On the third day, BatStateU faculty members brought SP counterparts for a learning journey to another campus that mimics a living laboratory, including a learning site for local and overseas students to collaborate on social innovation projects.

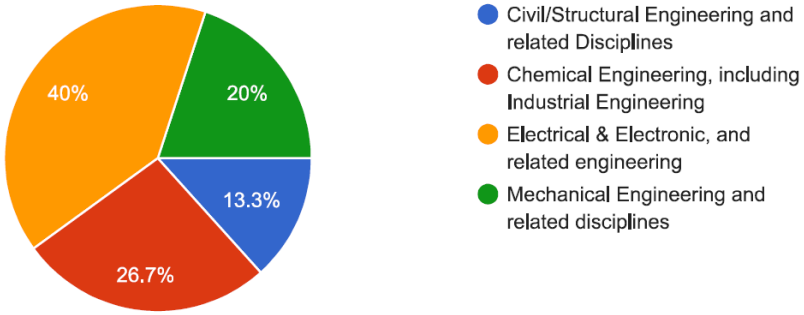


Figure 2. Participation of Faculty Members from BatStateU

Methodology

All attendees from SP and BatStateU were requested to share their experiences through short reflections or survey questionnaire in order to evaluate the usefulness of this P2PS pilot run. Five participants from SP who attended in the meeting at BatStateU shared their experiences through short reflections after they returning from the Philippines. Fifteen (15) BatStateU participants from various disciplines who attended the meeting completed an online survey questionnaire.

In the online survey questionnaire, participants were asked to share their opinions on the duration of the visit, specifically whether it was too brief, just right or too long. Participants were also asked to rate their satisfaction level with the P2PS exchanges between BatStateU and SP using a 5-point Likert scale. There were 3 open-ended questions for participants to share which aspects of the P2PS discussion went well, did not go well and what could be improved.

Learning Points from SP Participants

It was observed that BatStateU offers many sustainable development themed projects for students to work on through the virtual meetings between SP-DCHE and BatStateU-BSChE. The students of BatStateU won prestigious World Engineering Day Hackathon champion award in 2022 for their research work. Their research spans a variety of specializations with direct impacts on the community, showcasing the collaborative efforts of both students and faculty members. The complexity of the plant design outputs produced by the students further

highlights their capabilities. These projects provide inspirations to how SP-DCHE conceive projects with sustainability elements. SP-DCHE being in a first-world country faces different challenges where there are research and development institutes with more advanced technologies to provide support to the industries. With BatStateU's wealth of experiences in sustainable CDIO projects, SP-DCHE requested BatStateU-BSChE to share their experiences in preparing for the Hackathon and ideas of their sustainable CDIO projects. This enabled SP-DCHE and BatStateU-BSChE to work on a research topic that would benefit as applicable to both Singapore and Philippines. A prototype to condense water from air to generate potable water would be developed for two different intentions as one of the outcomes of this P2PS. SP-DCHE focused on the use of air conditioning technology which were installed in most offices and buildings while BatStateU-BSChE focused on the extraction of water from air for island installation as source of potable water.

The P2PS pilot run was indeed an enriching learning experience for the faculty members of SP with the following salient points:

- *Expectations from both parties* – SP introduced this P2PS initiative to BatStateU who just joined the CDIO community a year ago. Even though SP had earlier conducted various CDIO workshops for BatStateU faculty members, the trainers were not the same as the P2PS group from SP that visited BatStateU. So, both parties did not really know each other prior to the P2PS. The successful completion of the P2PS pilot run was credited to the open-mindedness of BatStateU faculty members, despite not having a full picture of how both parties would work with one another.
- *Trust and Comfort Level* - Given the limited time to get acquainted, it is challenging to establish the trust and comfort necessary for open exchanges. Differences in cultural backgrounds, values, and norms can lead to rushing through pleasantries to "get down to business" particularly for the visiting party, who may feel more pressure to meet deliverables. Suffice to say that the learning grew organically from the ensuring discussion rather than ascertained a priori.
- *Respect privacy and confidentiality* – SP hosted a common online repository where both institutions in this P2PS can access and use to exchange information. It serves to overcome the attachments of documents typical in email exchanges, which can lead to confusion over the several versions of documents used. It also stemmed with intention to respect the privacy and confidentiality of both institutions by restricting access to only faculty members approved by the respective institution to partake in the P2PS activities. BatStateU has been very generous with their sharing while SP exercised undue reservations because security classifications are mandated in the documents; though there is no requirement that any sharing had to be on "equal" basis.
- *Sustaining P2PS* – This is perhaps the most challenging aspect of peer-to-peer interactions. While face-to-face meetings can be more productive but it may not always be feasible. P2PS is unlikely to be a one-time event and follow-ups are typically necessary. As one participant noted, it needs to become "more routine work rather than an occasional deviation." Although initial contact may occur online, nothing compares to in-person meetings where both parties can truly get to know each other. Therefore, the challenge lies in leveraging technology for follow-ups after the initial meeting to maintain momentum until the next opportunity for an in-person meeting, such as at CDIO Asian Regional Meetings and/or CDIO International Conferences.

Learning Points from BatStateU Participants

BatStateU identified several areas for improvement based on SP's best practices. These include incorporating sustainability courses into the Chemical Engineering curriculum, continuously integrating sustainability into program delivery, leveraging highly specialized faculty members to teach these courses, and utilizing advanced workspaces and laboratories for both academic and industry purposes.

BatStateU recognized the need to benchmark their laboratories and explore collaborations to establish a laboratory for chemical industry processing, equipped with process control and automation. The Department of Chemical Engineering at BatStateU plans to develop a proposal for a chemical engineering laboratory, with the expected outcome to be achieved after benchmarking at SP during the CDIO Asia Regional Meeting on September 23-27, 2024. This laboratory will be installed in the proposed 7th or 15th story Engineering Building at BatStateU Alangilan Campus.

In addition to laboratory benchmarking, BatStateU-BSChE faculty members discussed with SP-DCHE faculty members to understand how SP-DCHE integrates sustainability into their curriculum, the processes they followed, and the impact on their students. To meet BatStateU's accreditation requirements, particularly the need for short courses for chemical engineering professionals, new agreements for a micro credentialing program will be established with SP. This program will involve collaborative teaching by specialized faculty from both institutions on mutually agreed topics.

Outcome from P2PS Visit at BatStateU

A survey was administered to 15 BatStateU faculty staff members at the end of the P2PS 3-day visit in October 2023 hosted by BatStateU and the survey outcome is further elaborated in this section. As shown in Figure 3, 80% of the faculty staff members from BatStateU found the duration of the visit to be sufficient while 20% of the faculty staff members felt that the duration of the visit was too short. Some comments received from the survey pertaining to the latter include “longer time for discussion” and “we were required to do many other things resulting less time for discussing some ‘meaty’ matters”.

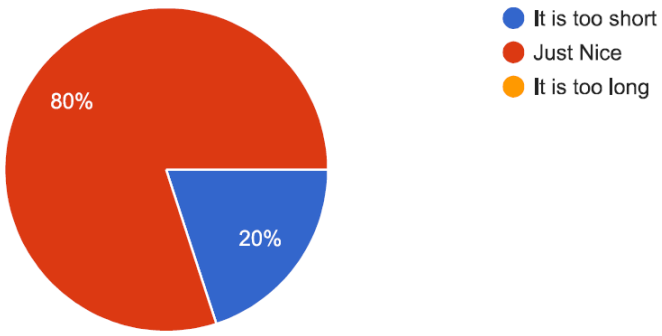


Figure 3. Survey Results on the 3-day P2PS Visit at BatStateU

All 15 faculty staff members from BatStateU are satisfied or very satisfied with the P2PS exchanges between BatStateU and SP. BatStateU faculty staff members commented the following:

- “the discussion serves as eye opener on what will be the direction of the BS Chemical Engineering as it is benchmark on the best practices of SP”
- “based on the discussion about curriculum and exchange of information, get a lot of insights on what could possibly be done in the curriculum for the next revision and how to include CDIO in the courses offered”
- “polytechnic education in Singapore is different compared to a polytechnic in the Philippines and it is enlightening that CDIO implementation can be done in varying degrees or levels”
- “sharing curricula and practices of both SP and BatSU went well and able to learn the same and different practices in both institutions”

In the survey, BatStateU faculty members were also asked to comment on the aspects of P2PS discussion that did not go well. 60% of the participants opined that all went well. The others commented that longer time would be beneficial to exchange notes between both institutions and the showcase of SP laboratories and facilities were limited to what were shown on videos and pictures.

BatStateU faculty members suggested that more faculty members should be involved to motivate and give insights on possible improvements in their respective teaching and workload to in the area of CDIO Framework and sustainability. Lastly, it was commented that P2PS should be an on-going collaboration because participants found that the sharing of best practices on module delivery and assessment rubrics as well as integrating sustainability aspects in capstone design projects can benefit students, stakeholders and targeted communities.

CONCLUSIONS

The experience and sharing of both SP and BatStateU paves way for the success of the P2PS program as initiated by SP. One key factor is the receptiveness of BatStateU to this process and the readiness they came forward to share what they had done. The extent of which BatStateU faculty members embraced the need to include sustainable development in their curriculum is admirable and served as a learning point for others wishing to do likewise. One important factor is that BatStateU top management took a proactive approach to design an online system that facilitates the tracking of not only the integration effort, but also help to demonstrate traceability of each course to specific United Nation Sustainable Development Goals (UN SDGs). Another factor that contributed to the smooth first face-to-face contact is that some faculty members from SP and BatStateU were acquainted from earlier engagements and a good understanding on the use CDIO for curriculum design. Building on this success, BatStateU may collaborate with other state universities and colleges in the Philippines and extend the collaboration with SP.

In conclusion, the willingness of both institutions to engage openly and respond constructively to each other's feedback has fostered a productive and enriching partnership. This collaboration not only improves the educational practices at both institutions but also paves the way for future peer-to-peer support initiatives.

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Peer-to-Peer Support (P2PS) REPORT Template between 2 Peers

Last Updated: 30/12/2022

Submitted to CDIO Council by Initiating Institution, i.e. the one that starts the P2P Support Process, documenting in this document what the Initiating Institution offered for sharing (SHOWN) and what it learnt from its P2PS Partner (LEARNT)

SHOWN (add rows as needed) Name of Initiating Institution: Singapore Polytechnic (SP) Program Shared: Chemical Engineering

Relevant CDIO Standard (One Row for One Standard)	Description / Activity (be concise, yet informative)	Key Features Shared (be concise, yet informative)	Dissemination (Y/N)	Dissemination Plan	Timeline / Action By
3. Integrated Curriculum	Use of Spiral Curriculum to incorporate data analytic skills and common core curriculum into DCHE curriculum	Assignment pairing with chemical engineering core modules and skill-based modules	Y	Other...	Oh Ai Ye shared slides presentation during actual visit to P2PS partner institution
5. Design-Implement Experiences	Use of Water Filter Challenge in a skill-based module	Incorporating the design and construction of a water filter with consideration of material availability and cost	Y	Other...	Oh Ai Ye shared slides presentation during actual visit to P2PS partner institution
6. Engineering Learning Workspaces	Energy and Chemicals Training Centre for training of skill-based modules	Use of Integrated Pilot Plant to illustrate a zero waste process with the use of DCS and IoT	Y	Other...	Oh Ai Ye shared virtual walk-through of facility during actual visit to P2PS partner institution

LEARNT (add rows as needed) Name of P2PS Institution: Batangas State University, Philippines Program Shared: B. Sc. in Chemical Engineering

Relevant CDIO Standard (One Row for One Standard)	Description / Activity (be concise, yet informative)	Key Features Learnt (be concise, yet informative)	Dissemination (Y/N)	Dissemination Plan	Timeline / Action By
3. Integrated Curriculum	Use of modules across different year of study to incorporate disciplinary core modules and soft-skill based modules	Both modules, Research Methods and Chemical Engineering Design 2, incorporates UN SDG goals as objectives to meet at the conceiving stage of each project-based modules.	Y	Poster	Eng. Mary Rose shared list of student projects with sample video and posters of students' work before actual visit and explained in detail during the actual visit
12. Program Evaluation	Illustrated the evaluation of students' end of semester assessment performance and course analysis using the institution's outcome based education framework.	Students Outcomes Assessment and Reporting System (SOARS) samples were shared to illustrate how institution graduate attributes and student learning outcomes are mapped to fulfil ABET, CDIO and SDG aims.	Y	Paper	Eng. Mary Rose shared samples before actual visit and explained in detail during the actual visit

Report sent by email to CDIO Office (info@cdio.org) for record	Please indicate Y or N ---------->	Y	---------->	Submission Date:
SENT BY: Name of Staff (and Name of Institution in brackets)	Oh Ai Ye (Singapore Polytechnic)			6 November 2023

CDIO Implementation

CONTINUAL IMPROVEMENT: SENSE-MAKING OF CONVERGENCE OF INSTITUTIONAL INITIATIVES ON DIGITAL TECHNOLOGIES

Sin-Moh Cheah, Mark Nivan Singh

Department of Educational Development, Singapore Polytechnic

ABSTRACT

The introduction of various educational initiatives in Singapore Polytechnic (SP), notably those based on using digital educational technologies (EdTech) tools at different levels of applications (institution, program, cohort, individual) had resulted in faculty feeling overwhelmed by the changes while trying to balance the demand of their day-to-day teaching duties. Examples include flipped classroom, growth mindset, self-directed learning and learning analytics, etc. Consequently, faculty failed to see the underpinning pedagogical considerations driving these initiatives and often tend to focus on implementing whatever a particular initiative required, “just to keep up”. On the other hand, the CDIO Framework has been used as a basis for continual improvement to guide various curricular redesign efforts over the years, whereby each initiative is implemented by referencing the relevant CDIO Standards. This paper proposes using the “lens of CDIO” to help faculty “connect the dots” between the seemingly disparate efforts to make sense of the situation, via a generic convergence model. For context, the paper first shares the key features of the initiatives for flipped classroom, learning analytics and ALeRT, which stands for Assessing Learning Regularly for Timely Support. The paper then shares how they can be harmonized via an initiative called Data-Enabled Flipped Learning (DEFL in short), within which another initiative of differentiated instructions was introduced. The stated overall aim of DEFL is to support the development of students’ self-directed learning competency. The paper provides explanations of how DEFL can be supported by the CDIO Framework as well as where it is situated in Academic Quality Management Framework of SP, to highlight the importance of the convergence as part of the institution’s drive towards continual improvement of its programs. Thereafter the paper also suggests how current on-going initiatives and future ones can also be harmonized using the proposed model, suggesting the model’s scalability to accommodate other initiatives. Examples where in-progress initiatives can be situated include a faculty digital competency framework and future learning workspaces. Lastly, the paper concludes with a discussion emphasizing the importance of having a ”human-in-the-loop” and continual faculty professional development for the integration of digital Edtech tools into the curriculum, calling for a concerted effort of faculty to engage with these tools in a productive way focusing on innovations in teaching and learning that maximize student learning outcomes.

KEYWORDS

Convergence, Flipped Learning, Learning Analytics, Digital EdTech Tools, CDIO Syllabus, Standards: 1-12

INTRODUCTION AND SCOPE OF THIS PAPER

From its inception, it is envisioned that programs that adopted the CDIO Framework for design or redesign will be able to deliver an education that is "constantly improved through quality assurance process with higher aims than accreditation" (from CDIO website, at https://www.cdio.org/cdio-vision). Over the years, various paper presentations had attested to the usefulness of the CDIO Framework in assisting programs to achieve good program quality assurance, as well as supporting program accreditation (Verhaevert, 2022; Truong, Ha & Le, 2018; Cheah et al, 2013; Georgsson & Holmgren, 2012; Levy, 2011; Gray, 2010).

Singapore Polytechnic (SP) adopted the CDIO Framework to underpin the revamp and redesign of project-based learning in a pilot study in 2004; that lead to the subsequent implementation in all engineering programs in 2007. Other non-engineering programs also used elements of CDIO in selected courses. Over the years, various initiatives have been introduced by SP to continually improve its programs so that they remain up-to-date and relevant to meet the demands of Singapore's workforce.

In recent years, SP has been leveraging the use of digital educational technology (EdTech) tools to drive these initiatives institution-wide. These initiatives aimed at improving SP's education system at different scales, from the individual-level up to the whole cohort-level. Programs adopting the CDIO Framework used it to continue to provide guidance in carrying out the required/necessary changes to the curriculum.

The non-exhaustive list below shows selected examples of recent-past efforts and current on-going initiatives.

- Flipped Classroom (Class-level)
- Self-Directed Learning (Individual-level)
- Teamwork Measurement (Group-level)
- Assessing Learning Regularly for Timely Support, or ALeRT in short (Individual-level)
- Learning Analytics – and later AI in Education (Cohort-level)
- Sustainable Development (Cohort-level)

Use of EdTech tools – digital or otherwise – needs to be built on pedagogical principles and theory of teaching and learning (Cowling et al, 2022). The introduction of these initiatives, coupled with the use of digital EdTech tools, had led to the unintended consequence of faculty feeling overwhelmed by the changes while trying to balance the demand of their day-to-day teaching duties. Often, they fail to see the underpinning pedagogical considerations driving these initiatives; other than they are all part of the institution's effort to improve the quality of its education.

This paper suggests an approach using the "lens of CDIO" to help faculty "connect the dots" between the seemingly disparate efforts to make sense of the continual improvement process. It first introduces selected recent SP initiatives involving the use of digital EdTech tools, namely flipped classroom, learning analytics, and differentiated instructions. Introduced over a spaced period, these initiatives eventually merged to form what is known as the Data-Enabled Flipped Learning (DEFL in short). Using the "lens of CDIO", how each initiative is implemented can be discerned through the application of relevant CDIO Standards. A convergence model of institutional initiatives guided by the CDIO Framework is then presented. The paper further discusses how current on-going initiatives, and future ones can also be harmonized using the convergence model.

THE CHALLENGE OF EDUCATIONAL INITIATIVES IN SP

The rapid convergence between digital EdTech tools and pedagogies provides great opportunities for faculty to tap into to increase teaching effectiveness, and improved students learning experiences and hence the learning outcomes (Brasca et al, 2022). Research had shown that faculty attitude can be an important factor in technology adoption in teaching and learning (Burch & Mohammed, 2019; Salas, 2016). Many authors had written on challenges faced by faculty that resulted in less-than-ideal adoption and use of digital technologies in education (see for example Mundy et al, 2012; Steel & Hudson, 2001). Georgina & Hosford (2009): examined how faculty technology literacy and technology training impact the integration of technology into their pedagogy. Their results showed significant correlations between technology literacy and pedagogical practice integration. Burch & Mohammed (2019) noted that there is not a simple model when it comes to augmenting classrooms with educational technology, hence a broad generalization can be problematic.

In the case of SP, recent surveys indicated that faculty are comfortable with using digital technologies in the classroom (Lee et al, 2024). The challenge that we faced is one of lack of understanding on how the different initiatives fits into the overall "big picture of educational improvement" instead of just "addressing each initiative as one comes along". The numerous initiatives introduced in the last few years had left some faculty feeling overwhelmed. Many failed to see the "connections" of the initiatives; treating them as independent of one another, and therefore are challenging to implement within the limited curriculum hours. Many are caught in a race to catch up and a sense of "learned helplessness" – a psychological state where one feels he/she has no control over a situation and is unable to escape. As a result, faculty to focus too much on their implementation before "the next big wave", instead of understanding the rationale for an initiative.

Brief Summary on Selected Initiatives: Flipped Classroom, Learning Analytics, ALeRT and SDL

SP introduced flipped learning to engage students in 2015 by starting with the School of Mathematics and Science and the School of Electric and Electronic Engineering. Several papers have been written on the use of CDIO Framework to implement flipped classroom. See for example, a series of integrated learning experiences (CDIO Standard 7) based on case studies had been reported as being delivered in flipped classroom format for learning chemical process safety (Cheah & Sale, 2017; Cheah, Sale & Lee, 2017; Cheah, Lee & Sale, 2016). In such applications, besides learning the technical knowledge for chemical process safety, students also learnt CDIO skills such as teamwork and collaboration, critical thinking, systems thinking, ethical reasoning, etc.

The COVID-19 Pandemic that started in late-2019 put added impetus to expand the use of flipped classroom to a much larger scale, as all lessons are now conducted online, mostly in asynchronous mode. The pandemic also saw wider adoption of digital educational tools to enhance teaching and learning, including the introduction of e-experiments to replace physical presence in laboratories due to campus closure. This period sees a significant increase in e-experiments developed using digital technologies such as Augmented Reality/Virtual Reality, interactive video, and digital twin. The CDIO Framework was once again used to guide the design of these e-experiments. Examples include use of blended learning (CDIO Standard 8) to promote growth mindset, virtual collaboration and resilience; and integrated learning experiences (CDIO Standard 7) 'operating' a virtual heat exchanger (Cheah & Wong, 2021); as well as development of self-awareness and safety mindset (Yang & Cheah, 2020).

In addition, the adoption of educational technology, in particular that of learning analytics, also contributed to the transformation of teaching and learning, especially in the context of flipped classroom. In 2019, SP introduced an initiative called ALeRT, which stands for "Assessing Learning Regularly for Timely Support" (see for example, Wan & Chong, 2020). Use of ALeRT strives to improve students learning by providing near-real time feedback to students data collected from students' responses to online quizzes and displayed on performance dashboard for each student. This is followed in 2022 with the introduction of differentiated instruction. Differentiated Instruction is a systematic educational approach in which teachers modify content, teaching and learning activities to honour the range of student backgrounds and maximizes their learning opportunities and capacities (Tomlinson, 2017).

Another important development in SP, just before the COVID-19 Pandemic was the introduction of self-directed learning (SDL) competency in students in 2018. This initiative was SP's response to Singapore's SkillsFuture Initiative, which was formulated to address the challenge of Industry 4.0 (Cheah & Leong, 2018; Cheah & Yang, 2018). One of the four strategic thrusts of the SkillsFuture Initiative was the development of lifelong learning competency among Singaporeans. Self-directed learning is one of the key competencies that supports the development of lifelong learning competency (Boyer et al, 2014). Diplomas adopting the CDIO Framework again used it to guide the design of integrated learning experiences to systematically integrate underpinning skills and attitudes needed – as per the CDIO Syllabus – to progressively develop SDL competency in students. See for example Cheah (2020), Cheah, Wong & Yang (2019).

Convergence: Data-Enable Flipped Learning

The SP Data-Enable Flipped Learning (DEFL) Model as shown in Figure 1 was introduced in 2022. It is the result of the convergence of flipped classroom, learning analytics (ALeRT) and differentiated instruction, mediated by the use of digital EdTech tools. It aims to enhance student learning outcomes by fostering their active engagement in the learning process to further enhance their SDL competency.

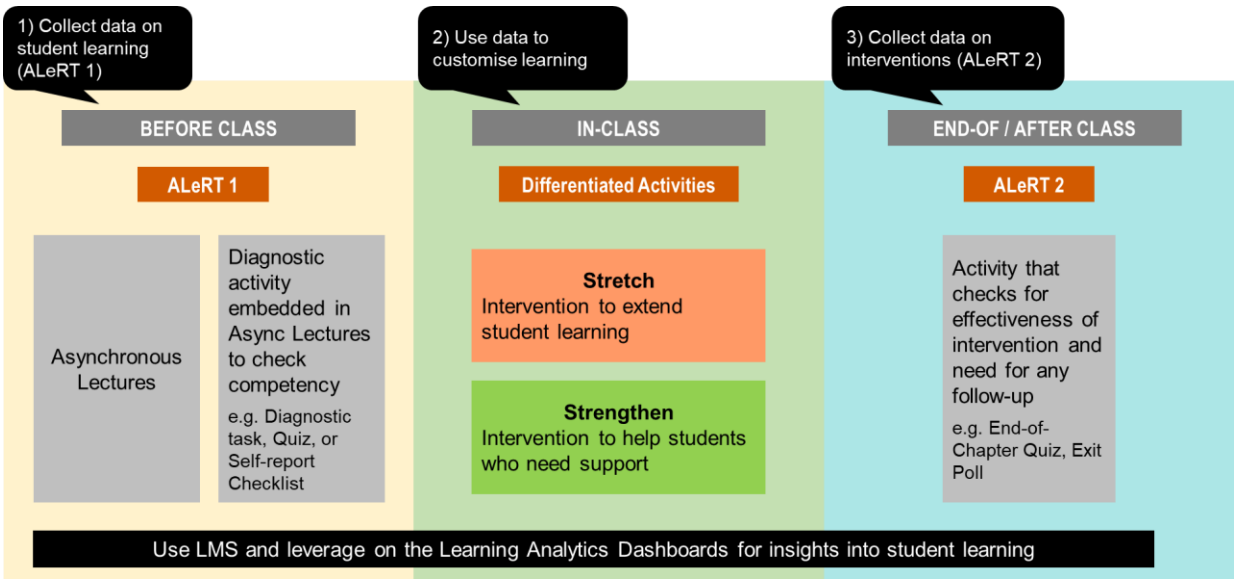


Figure 1. Singapore Polytechnic Data-Enabled Flipped Learning (DEFL) model.

A use case of DEFL was presented by Wan, et al (2024). Briefly, there are three stages to the DEFL model, and they are briefly explained below:

- ***Stage 1 Before Class - Collect and analyse data on student learning (ALeRT1):*** Students go through the materials asynchronously in the Learning Management System (LMS) and complete quiz/quizzes in the LMS to assess their understanding. The assessment data is diagnosed and given to lecturers via the LMS Dashboard or downloadable reports. Lecturers analyze and use the data to plan for the In-Class Stage next.
- ***Stage 2 In-Class - Use data to customize learning (Differentiated Activities):*** Lecturers used different instruction to different groups of students as discerned from the diagnostic results. On one hand, "stretch" interventions are provided to better-performing students to further their learning. On the other hand, "strengthen" interventions are extended to weaker students who need more support.
- ***Stage 3 End-of/After Class - Collect data on interventions (ALeRT2):*** Another round of diagnostic survey is administered in the LMS for lecturers to assess the effectiveness of the interventions and identify additional requirements for any follow-up, for weaker students, such as further scaffolding or individual consultations.

The CDIO Framework provides guidance to the implementation of DEFL via the use of CDIO Syllabus and referencing the relevant CDIO Standards, as shown in Figure 2.

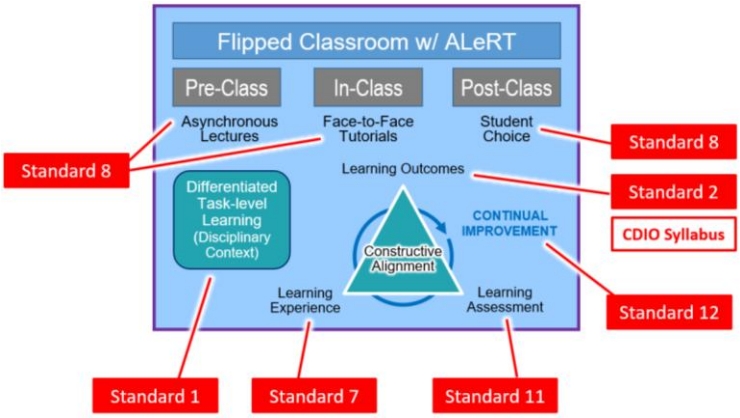


Figure 2. How CDIO Supports the Implementation of DEFL

USE OF CDIO FRAMEWORK TO ADDRESS RECENT SP EDUCATIONAL INITIATIVES

The "lens of CDIO" is one of continual improvement, where guidance is provided by Core Standard 12 Program Evaluation. It offers a good approach to help address the challenges faced by faculty in appreciating the myriad of initiatives aimed at improving student learning using EdTech tools. This will be expounded below.

Recap: Use of CDIO to Support Program Continual Improvement

Cheah et al (2013) had reported on the use of CDIO Self-Evaluation to complement SP's Academic Quality Management System that drives the continual improvement effort of all programs in the institution. The basic approach is straight forward: any initiative introduced can be viewed and understood from the "lens of CDIO" with regards to its implementation, by visiting the 3 fundamentals of the CDIO approach to curriculum design/redesign:

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?

With regards to continual improvement, the CDIO self-evaluation process from CDIO Core Standard 12 Program Evaluation had been shown to be complementary to the SP Academic Quality Management System (AQMS) and useful to guide program review (Cheah, Koh & Ng, 2013). Figure 3 shows the SP AQMS and how the different elements are supported by the CDIO Standards. DEFL is also shown, as part of the curriculum delivery system.

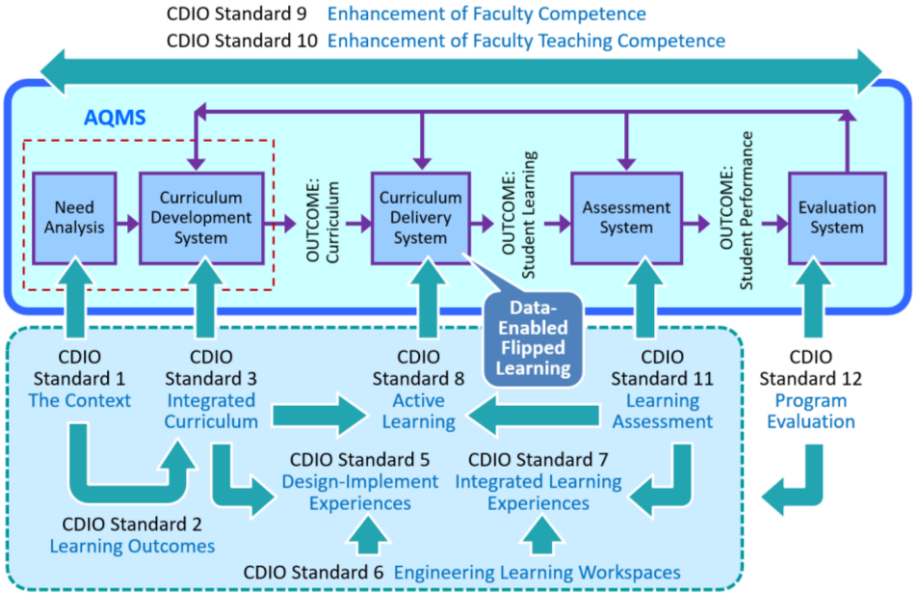


Figure 3. How CDIO Supports the SP Academic Quality Management System

Towards a Convergence Model of Curriculum Enhancement using CDIO Framework

Generalizing from the above, we can use the "lens of CDIO" to carry out similar analysis to investigate how other initiatives in SP fits within the continual improvement process. The model is shown in Figure 4, where initiatives in SP are grouped into 4 broad categories of Pedagogy & Competency Framework, Digital Technologies, Student Engagement & Learning, and Infrastructure and System Support. These 4 categories mutually support and impact one another, as shown by the 6 double-headed arrows. An example of SP initiative in each category is provided. The various core standards are shown "surrounding" the 4 broad categories of SP initiatives, which in turn are pushing towards developing SP's 6 graduate attributes.

Figure 4 also highlights a key aspect of continual improvement emphasized in CDIO Framework: The role of faculty in implementing the initiatives. These are the professional development of faculty teaching competence in personal and interpersonal skills, product, process, system, and service building skills, as well as disciplinary fundamentals (CDIO Standard 9); plus the competence in providing integrated learning experiences, in using active and experiential learning methods, and in assessing student learning (CDIO Standard 10).

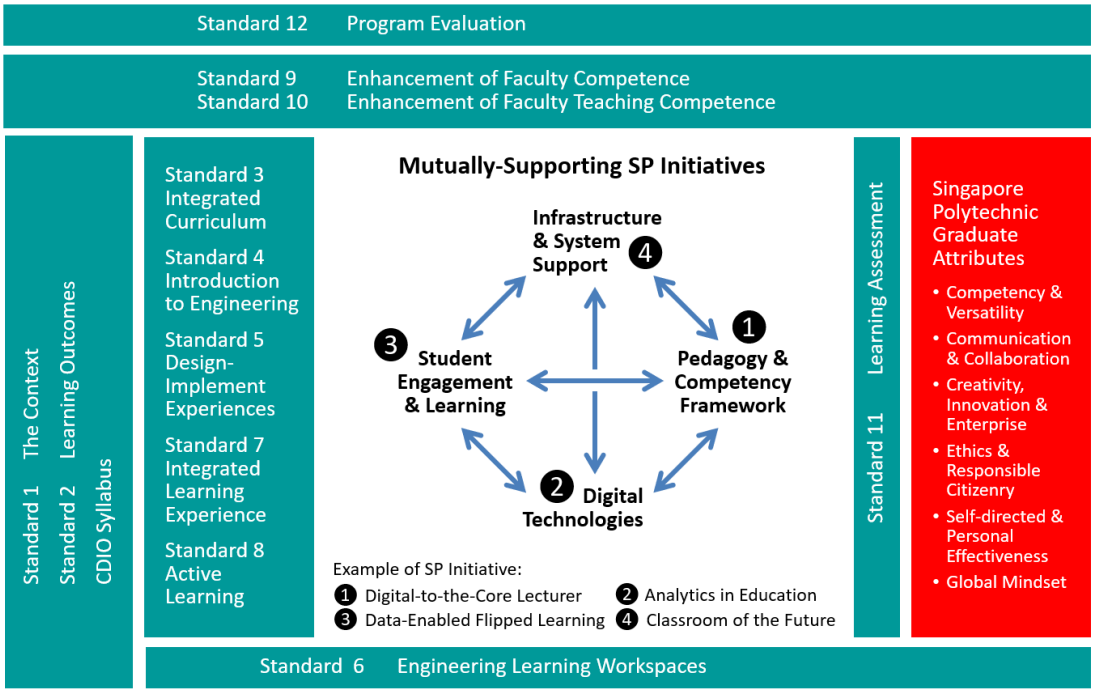


Figure 4. Convergence Model of SP Initiatives Guided by CDIO Framework

Convergence: Adding other Existing SP Initiatives to the DEFL

Continuing with the DEFL example covered earlier, this model can be used to demonstrate how other initiatives contribute to the continual improvement effort; i.e. helping faculty to "connect-the-dots" in understanding how and why each initiative is introduced. More importantly, it emphasizes the importance of continuing professional development of faculty not only in data literacy, but also in designing learning tasks that leverage of the affordances of EdTech tools. To this end, SP introduced an initiative titled "Digital-to-the-Core" (DTTC) lecturers which seeks to equip lecturers with the capability to use EdTech for teaching and learning. Another initiative introduced, is the project on "Classroom of the Future" (CotF). Collectively, DEFL, DTTC and CotF can be seen as a wider effort towards utilization of digital technologies to improve student performance – more specifically, a convergence on how DTTC and CotF supports DEFL, is shown in Figure 5.

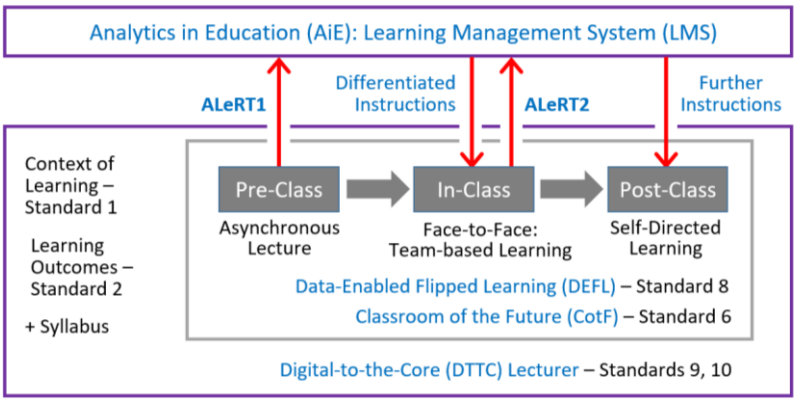


Figure 5. Convergence – How DTTC and CotF supports DEFL

DISCUSSIONS: USEFULNESS OF CONVERGENCE MODEL

While not directly related to convergence of any EdTech tools, one aspect worth mentioning of the model is that it highlighted the role of the CDIO Framework. This is significant because not all of the 43 programs in SP that implemented DEFL since 2022 has adopted CDIO. It is therefore attractive for these programs to adopt the CDIO Framework.

In addition, it is also noted that most modules that implemented flipped learning had used the online learning component to promote student learning of domain (technical) knowledge, more or less as replacement of traditional face-to-face lectures. It is therefore imperative for these modules – whether the program adopted CDIO or not – to include the integration and the development of skills and attitudes that go hand-in-hand with the application of the module's domain knowledge.

It would be relatively straight-forward for programs that adopted CDIO to introduce skills and attitudes development in DEFL. More importantly, programs that implemented DEFL but yet to adopt CDIO can benefit from guidance provided by the various CDIO Standards. These programs can integrate various skills and attitudes that support the acquisition of domain knowledge, e.g. virtual collaboration, ethical reasoning and resilience, much in the same manner for programs that have adopted CDIO.

The convergence model (Figure 4) is also broad in its "coverage" of the various SP initiatives. This means that it is scalable to accommodate other initiatives not yet introduced at the present, which may fall into any one of the 4 categories. Further convergence can be expected, when lifelong learning (which builds on SDL competencies), use of data analytics for sense-making (e.g. via data visualization), virtual collaboration becomes more important in the near future. At the regional and global levels, we already witnessed the use of big data from industrial internet of things technologies to support sustainable development. That is also the reason for SP to introduce its common core curriculum to acquaint students with skills that can be used to address sustainability issues (see for example, Cheah, Lim & Chao, 2022).

Plausible Future Convergence: Possibility of Adding Yet-to-Formulate Initiatives

The concept of DEFL has the potential to further enhance student engagement by adopting it to other learning touch points such as laboratory experiments or projects. This allows the development of skills and attitudes that in classroom settings, cannot be adequately developed due to the lack of learning context afforded by suitable engineering learning workspaces.

A hypothetical application modelled after DEFL is shown in Figure 6. Although hypothetical, it is in fact highly plausible. As noted earlier, many e-experiments have been introduced during the COVID-19 pandemic. Similarly, a large number of video recordings have been curated or assimilated during the period. In fact, a new initiative called Video Content Management System (VCMS) is already underway at the time of this paper. Many experiments requiring students' physical presence in the laboratory or workshop already require students to engage in some form of preparation prior to the laboratory or workshop sessions, and likewise require students to apply or explain how they are going to apply what they learnt from the laboratory or workshop to other scenarios. A Laboratory of the Future can also be envisioned. Hence, Figure 6 shows a fictitious initiative Evidence-based Virtual Experiment that can serve similar function as DEFL that brings together various initiatives mentioned here. Faculty competency under the DTTC initiative also needs to be further enhanced.

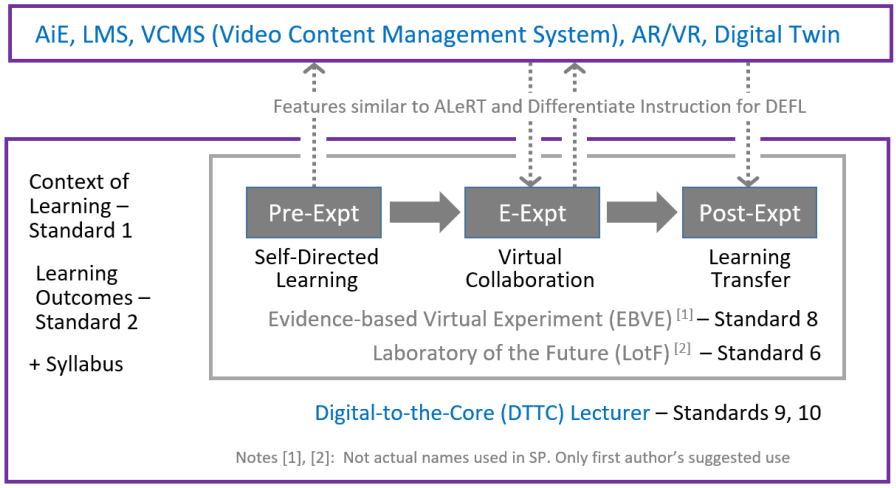


Figure 6. Convergence – Application of Hypothetical but Plausible Scenario

Convergence: Human-in-the-Loop

The discussions thus far will not be complete without referring back to the aspect most impacted by permeation of digital EdTech tools into teaching and learning: the faculty themselves, and the resulting confusion among them of the many initiatives introduced. In today's educational context, with the prevalence in use of technology, most notably artificial intelligence in the learning environment, the role of faculty as "human-in-the-loop" – a term largely credited to Monarch (2021) – in now greater than ever. The present convergence of initiatives (DEFL, differentiated instructions, and CotF), along with the proposed future convergence as described previously, are now 'merged' into the larger DTTC initiative as part of SP Initiative of Analytics in Education (AiE).

From the "human-in-the-loop" perspective, a faculty now embodied multiple roles of not only in using Digital EdTech tools in teaching and learning, but also the overseer of its ethical applications. At this point, it is worth mentioned an earlier effort of Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006), which identifies three types of knowledge that an educator brings when planning to integrate technology into a lesson: technological knowledge, pedagogical knowledge, and content knowledge. While each of the 3 key domains of knowledge is important in its own right, it is their creative combination that can create effective learning experiences for students.

The convergence also prompted us to rethink the saying "pedagogy before technology" (Watson, 2001). Many faculty, who are not part of a pilot group for were tasked to lead any digital Edtech tool initiative, often felt they are playing catching up when a technology is seen as imposed on them following the pilot effort. They may not feel comfortable over the choice of such tools with respect to their specific modules; a very opposite situation of "technology before pedagogy". While not desirable, attempts to defer technology use for later consideration is also problematic, as technology use in today's context is now very much interconnected with the teaching approaches, learning scaffolds and assessment methods used. Literally leave out technology till later can result in faculty susceptible to an inadequate appreciation of complexity relating to how is interwoven into educational activity (Fawns, 2022). He advocated the use of an "entangled pedagogy" – a model that encapsulates the mutual shaping of technology, teaching methods, purposes, values and contexts (Fawns, 2022).

As the saying “We shape our tools, and thereafter our tools shape us” goes, the relationship between human and technology is two-way: Humans create inspiring and empowering technologies but also are influenced, augmented, manipulated, and even imprisoned by technology, depending on the situation and how the technology is used (Hurme & Jouhki, 2017). The human elements are intertwined with the process of using digital EdTech tools. The “human-in-the-loop” approach is important in ensuring that technology use – albeit in an “entangled” manner – remain focused on improving student learning.

Implications for Faculty Professional Development

During the COVID-19 Pandemic, the emphasis on using digital EdTech tools is to ensure continuity of education to students, despite campus closure. The rapid pivoting to online teaching and learning during this period much curriculum had being digitized and transmitted via technology rather than transformed by it (Cowling et al, 2022). Such a pivot also meant that few faculty were sufficiently prepared for learning environment centered around technology (Cowling et al, 2022).

We therefore need to improve such online offerings post-COVID. Some offerings during the period of campus closure are temporary legacies that require undoing, while good practices need to be identified, retained and improved upon (Crawford, 2021). Examples are the largely PDF versions of the lecture notes, PowerPoint slides (without or with minimal narratives). Kehrwald & Parker (2019) referred to the act of putting learning materials online that are largely static as “shoveling”, and the digitized documents as “shovelware”. Furthermore, the growing availability and capability of digital EdTech tools will allow ever greater exploration of teaching and learning in new ways; which can even change the way technology is used. Generative AI is a case in point. Effective transition to the digital platform requires careful considerations of the cognitive, affective and behavioral changes that formed a part of the transition (Cowling et al, 2022). Adapting digital technologies to teaching and learning cannot be a one-size-fit-all approach that focused largely on technical knowledge. Of importance is the alignment between the digital EdTech tools used with the pedagogical and technical knowledge (Børte & Lillejord, 2024), where the choice of pedagogy or combination of pedagogies will address all the 3 aspects of learning: cognitive, affective and behavioral changes.

The SP DTTC Initiative is envisioned to serve such a need. In our context, a DTTC lecturer is one who goes beyond just “teaching” or “lecturing”, in using technological tools to draw insights via data analytics, to designing and delivering effective learning interventions that maximize. In its current form, it is still very task-oriented, focusing of competencies of lecturers in using digital technologies including learning analytics in the design of EdTech-enabled learning experiences. The development of the DTTC Framework is still an on-going process, as it has to be continually reviewed, revised, and updated to accommodate emerging new opportunities and/or challenges. A case in point is the ethical use of Generative AI (GenAI) in teaching and learning – yet another convergence! Recently, UNESCO just released its guidance document of AI framework for teachers (UNESCO, 2024) which will necessitate a new round of review.

The convergence model can serve as a basis for designing faculty professional development programs under the DTTC banner. This has the advantage of empirically testing the model. The goal of education is always to maximize student learning outcomes. Efforts need to be directed towards preparing faculty to leverage on affordances from digital EdTech tools to introduce educational innovations, guided by the CDIO Framework.

CONCLUSIONS

This paper showed that the CDIO Framework, which demonstrated its resiliency over the years, remains to be relevant with the DEFL Model. This is perhaps hardly surprising, since all SP initiatives are solidly grounded in strong teaching and learning foundations; which is the same approach that SP used in its adoption of CDIO. This paper suggested that the CDIO Framework can be used to reconcile various technology-based initiatives introduced in an institution, helping SP lecturers make sense of the mutual dependency between technologies and pedagogies used, on attainment of desired student learning outcomes. A convergence model is suggested in this paper, where it can be scaled to accommodate other future initiatives to continue to "connect the dots" for lecturers.

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REFLECTING ON REFLECTIONS – LEVERAGING STUDENT FEEDBACK FOR CONTINUOUS PROGRAM DEVELOPMENT

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ABSTRACT

A system, named Reflex, for handling reflection documents is presented. Writing a reflection document is a mandatory last step when carrying out Master's or Bachelor's theses within all education programs at the Faculty of Science and Engineering at Linköping University. In the reflection document the students are expected to reflect on both the thesis work and the outcome of the entire education program. The reflection is structured according to the four sections of the CDIO Syllabus plus additional aspects around the process of the thesis work and the program as a whole. Reflection documents have been used for more than ten years, but via the introduction of Reflex in 2023 the process is entirely electronic and all texts from the reflections are stored in a searchable database. This enables efficient and systematic analyses of the texts, which can be used for evaluations of entire programs as well as selected aspects. Two examples of such analyses are presented in the paper. In addition, the thesis work process is presented, together with a description of how the system Reflex works.

KEYWORDS

Reflection, thesis, program evaluation, CDIO Syllabus, Standards: 2, 11-12

INTRODUCTION

Reflections for learning and continuous development is a wide field, and the literature in the field is comprehensive. The aim of the paper is to present an example of such an activity in terms of a reflection that is carried out as a last step of the thesis work and how that can be used also for continuous development of education. In literature, the work in (Kolb, 1984) about experiential learning and Kolb's learning cycle is a key reference. According to (Kolb, 1984) the learning cycle consists of the stages (i) Concrete Experience, (ii) Reflective Observation, (iii) Abstract Conceptualization, and (iv) Active Experimentation. See also (Gibbs & Habeshaw,1989). Within the CDIO community there are several references where reflections in different forms have been studied, where (Junaid *et al*., 2018) and (Cosgrove & O'Reilly, 2019) are two examples. In addition, (Cheah, 2022) presents an excellent overview of the field with an extensive list of references related to reflections. Also, in project-based activities reflection at the end of the project is often used as a last step. See, for example, (Andersen & Schwenke, 2013) and (Lööw, 2009).

There are many examples of the use of reflections within the courses at the Faculty of Science and Engineering at Linköping University. In many cases this takes place within project-based courses. The reflection document at the end of the Master's and Bachelor's thesis was introduced around 2011 as a mandatory last step of the thesis work in all education programs within the Faculty of Science and Engineering at Linköping University. One purpose of the reflection document is to make the student reflect upon the execution of the final major task before graduation, and a second purpose is to give feedback to the program management concerning how well the education program has prepared the student for the intended role as engineer. The reflection document is structured according to the four sections of the CDIO Syllabus. In addition, there is one section dealing with the thesis work process and a concluding section. For each section there are some guiding questions supporting the students when writing the reflection. The sections and the guiding questions are presented in the Appendix. During the spring semester of 2023 the new web-based system, named Reflex, was introduced. Reflex is based on a combination of various administrative systems, but the technical details will be omitted here. The main messages of the paper are the following:

- Reflex is a web-based system for management of the reflection documents that are written by all students as part of the thesis work.
- Reflex has solid connections to the CDIO framework via CDIO Standard 12 about program evaluation. In addition, the reflection document is based on the CDIO Syllabus.
- Since the reflection document is mandatory, this gives an evaluation system with 100% response rate.
- Reflex enables various types of analyses about the students' view of their thesis work and education program.

It should be stressed that the paper is not claimed to be a scientific contribution concerning student satisfaction or similar. Instead, it is intended to present the implementation of a system that systematically collects and stores students' reflections, is easy to use for both students and examiners and enables various types of analyses based on the collected data.

THE CDIO FRAMEWORK

The fundamental aim of the CDIO framework is to educate students who are "ready to engineer" and to raise the quality of engineering programs. See (Crawley *et al*., 2014) and the web site (CDIO Initiative, 2024). The framework relies on four key components:

- A “definition” of the role of an engineer.
- Goals for the desired knowledge and skills of an engineer listed in the document the (CDIO Syllabus, 2024).
- Goals for the properties of the engineering education program collected in the document (CDIO Standards, 2024).
- Methods for systematic development and management of education programs.

According to the CDIO framework, see (Crawley *et al*., 2014) page 50, the goal of engineering education is that every graduating engineer should be able to *Conceive-Design-Implement-Operate complex value-added engineering products, processes, and systems in a modern, team-based environment.* Adopting this definition, it is natural to design and run an engineering education program with this in focus. The CDIO Syllabus is a list of the desired knowledge and skills of a graduated engineer, and the (CDIO Standards, 2024) is a set of twelve components that are crucial for designing and running an engineering program that enables the students to reach the desired knowledge and skills. Linköping University was one of the four original participants in the CDIO Initiative, and during the first years the efforts were concentrated on the Applied physics and electrical engineering program. Gradually the framework was applied within other engineering areas, such as Engineering biology and Mechanical engineering. The CDIO framework is nowadays in widespread use within the faculty of Science and Engineering at Linköping University and the CDIO Syllabus has been extended and adapted to enable programs in, e.g., natural sciences to be included. The framework has also been disseminated outside the technical faculty and has been applied successfully in the re-design of the Bachelor’s program in biomedicine.

MASTER’S THESIS WORK PROCESS

Reflex is used both at Bachelor and Master level, but the focus here will be on Master level, where the execution of the thesis work follows the structured process which is described below. This represents the process for the students following the five-year programs, where the thesis work is carried out during the spring semester of year five. The steps related to the reflection document and Reflex are presented in italics.

1. During the fall semester of year five the student starts looking for suitable tasks for the thesis work via discussions with e.g. suitable companies and potential examiners at the university. With the successful outcome of these discussions the student is assigned an examiner and a supervisor at the university and an industrial supervisor when the work is going to be carried out in industry.
2. In the next step the student registers for the thesis work in the administrative system Ladok.
3. *After the student has registered for the thesis work, Reflex automatically sends an email to the student asking the student to, via an included link, enter the name of the examiner and the specialization the student follows within the education program. Additional information related to the student is taken from Ladok.*
4. The first two to three weeks of the thesis work are spent on developing a planning report, which includes the problem formulation, an initial theory base with references, and a time plan for the work. The document is iterated until it is approved by the examiner, and the actual work can start.
5. After roughly ten weeks of work there is a mandatory half-time check where the student presents how the work has developed and how well it follows the time plan. Feedback is given from both the examiner and the supervisors.

6. *The nominal time for the thesis work within the five-year education programs is 20 weeks, and after 15 weeks from when the student registered Reflex automatically sends an email to the student stating that a reflection document is ready to be filled in together with a link to the web-based form.*
7. At the end, the thesis work is presented via a written report and a public oral presentation. The oral presentation is followed by a discussion (opposition) by another student, where the task is to discuss the work from a technical viewpoint and bring up e.g. assumptions and limitations for the work. After the oral presentation the student carries out the final revision of the report, which then, in most cases, is uploaded to the university database and by that is made publicly available.
8. *To be able to cover the entire thesis work the student typically fills in the reflection document as the very last step of the thesis work process. i.e. after both presentation and opposition.*
9. *Once the reflection document has been filled in, the system Reflex sends an email to the examiner stating that there is a reflection document to evaluate. The task for the examiner is not to evaluate the opinions of the student but rather to check whether the student has made a serious attempt to reflect upon the thesis work from different viewpoints. The examiner can either approve the document directly or ask for revisions, based on comments that are sent to the student. Also, when the document is approved the examiner can give some final comments to the student and, of course, reflect on the reflections if there is something in the working process that ought to be reconsidered.*

The first big advantage with Reflex is that the process is integrated into one system with several steps generated automatically and that no documents need to be sent back and forth. The second big advantage is that all texts are stored in a searchable database, and that the documents can be filtered according to, e.g., education program, specialization, and department. Two examples of analyses of reflection documents are presented below. The reflection document is mandatory but not anonymous, and parallel to the reflection document the student has the possibility to fill in a brief anonymous course evaluation regarding the degree project course.

USE CASES

To illustrate how the material collected in Reflex can be used, two use cases are presented. The use cases are taken from two of the biggest five-year engineering education programs at Linköping University. The purpose of the use cases is to illustrate how the text that are collected via Reflex can be analyzed, both manually and via AI-tools. The case studies are not meant to be research studies concerning student satisfaction, but that can be an interesting topic for future work.

Industrial Engineering and Management

The first case is from the five-year Industrial Engineering and Management engineering program, which annually admits approximately 180 students. In the fall of 2023, the program development team, consisting of teachers, supporting staff, and students, manually analyzed students' reflections on the program in general, collected under the concluding section. See the Appendix. Each team member read 10 randomly assigned reflections and made individual notes on what students highlighted in various areas. The team then reviewed these reflections as a group and compiled a collective thematic analysis. Here is a summary of the collective findings:

Contribution of the Thesis Work to Educational Goals

The students expressed high satisfaction with their thesis work, highlighting several key benefits:

- Increased responsibility due to less instructions
- Ability to structure and solve problems
- Collaboration
- Interaction with the industry – practical and academic knowledge tested on real-world problems at case companies
- Independent work
- Improved communication skills in presenting technical and scientific results, both orally and in writing.
- Analytical thinking

Sustainability Perspectives in Education

Opinions on sustainability integration are mixed:

- Some students appreciate the inclusion of sustainability but a lack of SDG (Sustainable Development Goals) in one of the relevant profiles
- Others feel the coverage is insufficient and superficial
- Social sustainability is notably lacking
- One sustainability dedicated course is recognized for its focus on sustainable development
- Some students perceive sustainability as being consistently integrated into all courses, while others believe it constitutes only a minor component of the overall education

Suggested Improvements

- Reconsider the use of ADA as a programming language
- Balance technical and economic credits, with more flexibility in technical courses
- Increase the use of English in coursework
- Strengthen industry connections and practical applications
- Distribute mathematics courses more evenly
- Technical focus in applied mathematics.
- Offer a technical track in applied mathematics

Preparedness for Working Life

Students unanimously feel well-prepared for their careers and are satisfied with their education.

The team also explored the utility of Chat-GPT in compiling the raw data. While the AI-generated results exhibited partial alignment with the team's conclusions, the analysis was not deemed entirely accurate. Nevertheless, the team derived numerous new insights from the non-AI revision and confirmations pertinent to the development work for program enhancements. The students also underscore the significance of having their reflections read by their teachers rather than an AI tool to keep motivation and the feeling of meaningfulness for the task. They articulated a preference for a "real" recipient of their thoughts and opinions. The Reflex system has facilitated the team's engagement with students' reflections on the design and content of the programs in a straightforward and comprehensible manner. Hence, the team will continue utilizing Reflex for development purposes and during this year's

revision, the team will review another section of the reflection documents to assess the progress of skills.

Mechanical Engineering

The second case study examines reflection documents written by students enrolled in the five-year engineering program in Mechanical Engineering, which admits approximately 120 students annually, and the Mechanical Engineering Master's program, which admits around 30 students each year. During the same period as the first case, in the fall of 2023, the program development team for the Mechanical Engineering programs conducted an analysis of four key questions related to the thesis process namely: (1) How has the complete process of completing the degree project within Linköping University worked? (2) A degree project is to correspond to 20 weeks of full-time work. How well does 20 weeks of full-time work correspond to the time you have used? (3) What aspect of your Master thesis gives you the greatest satisfaction, considering both the result and the execution? (4) What would you do differently, given the opportunity to repeat the degree project? Based on these, the questions guiding the team's analysis of the students' reflections were:

1. What are the students' perceptions of the thesis process, and what areas for improvement can be identified?

2. Can analytical tools be utilized to facilitate the review process, and if so, which tool and how should it be applied?

Early in the process, it became clear that manually reading all the reflection documents in full each year for every program managed by the team would be too time-consuming. As a result, a parallel question emerged regarding the potential use of tools to streamline the analysis (see question 2 above). One team member conducted the analysis using three approaches: manually, with the aid of NVivo14 — a qualitative analysis software commonly used in research — and automatically, using Kahubi and ChatGPT, both of which are AI-assisted tools. The results of the automated analyses were compared with the manual method to evaluate their accuracy and alignment, to determine whether these tools could be employed for systematic analysis in future evaluations.

The analysis revealed that students are generally very satisfied with the thesis process, and no significant systematic issues were identified in either of the two programs. The challenges raised were primarily specific cases, such as instances where supervision had not worked effectively or where the assignment from or interaction with the company had been problematic. Through the students' reflections on what they found challenging, issues such as time management and method selection were identified. The team recognized that this information is valuable to share with those supervising the students. In this way, the results of the analysis not only benefit the program development team but also provide actionable insights for the instructors involved. Since no major areas for improvement or systemic problems were identified, the team concluded that this serves as a solid baseline for future analyses. This baseline will enable comparisons over time to monitor if conditions worsen or remain stable.

Following the analysis, ChatGPT was deemed the most suitable tool for facilitating the analytical work compared to NVivo14 and Kahubi. However, it became evident that crafting an effective prompt is crucial, particularly one capable of capturing outliers, such as cases where the process had not functioned well. This is important because ChatGPT generated general conclusions tending to be overly positive when most responses are positive. To address this

limitation, the team emphasized the importance of complementing the AI analysis with random sampling and a thorough review of selected reflection documents to ensure a more balanced and reliable assessment. During team discussions, it was noted that the Reflex system significantly simplified the process of collecting all reflection documents in a centralized location, making them accessible to a wider range of stakeholders. Additionally, Reflex facilitated the aggregation and extraction of information specific to individual programs, enabling systematic analysis of how each program's students perceive the thesis process. This integration of tools and methods has enhanced the team's capacity to identify trends and areas for improvement in a structured and efficient manner.

SUMMARY

Writing a reflection document is a mandatory last step in all Master's and Bachelor's theses within the Faculty of Science and Engineering at Linköping University. A web-based system, named Reflex, for managing reflection documents has been presented. Reflex has solid connections to the CDIO framework via CDIO Standard 12 about program evaluation. In addition, the reflection document is based on the CDIO Syllabus. Since the reflection document is a mandatory part of the thesis work, this gives a 100% response rate. The system enables various types of analyses about the students' view of their thesis work and education program, and two case studies have been presented. In the case studies both manual analysis and analysis using AI-tools have been used.

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APPENDIX

The significance of knowledge of the subject for the execution of the degree project

To what extent has the knowledge of the subject you have gained during the courses given in the programme been sufficient for the execution of the degree project?

What new knowledge has it been necessary to acquire in order to carry out the degree project?

To what extent have the degree project and the study programme enabled a scientific approach in the degree project?

The significance of your personal and professional skills and the approach you have taken for the execution of the degree project

To what extent have the courses given in the programme given you the ability to solve problems and take the initiative? To what extent have they given you the ability to take responsibility as required by the degree project?

To what extent have the courses given in the programme given you the ability to make the ethical assessments within engineering that the degree project required?

To what extent has the work involved experimentation, simulation, testing, and other investigative activities?

What resources have you used to find the literature required to carry out the work?

How much time did you devote to planning the work, and how did the planning help you in the execution of the degree project? How much did the planning report and the mid-way review help you in the execution?

The significance of working in a group and communication during the degree project

If the degree project has been carried out together with another student, how has the work been divided between you, and how has collaboration worked?

To what degree has the work been carried out independently of the supervisor and examiner?

What has been easiest and what has been most challenging when writing the report from the degree project, and when preparing and giving the oral presentation?

To what extent have your language skills (in English or another language) been sufficient?

To what extent have the courses of the programme given you the knowledge and skills necessary to examine and comment on the work of someone else, in the role of opponent?

The degree project from an engineer's perspective – planning, development, realisation and operation of technical systems, taking into account commercial and societal needs and demands

To what extent has it been natural for you to place the degree project into a commercial and societal context, including environmental and other aspects of sustainability?

Can your degree project be seen as part of the development of products, processes or systems? If so, in what way?

The degree project process

How has the complete process of completing the degree project within LiU worked? Consider the steps of finding a topic for the degree project, having an examiner and supervisor at LiU assigned to the degree project, writing the planning report and holding the mid-way review, submission and opposition.

A degree project is to correspond to 10 - 20 weeks of full-time work. How well does this correspond to the time you have used?

What aspect of your degree project gives you the greatest satisfaction, considering both the result and the execution?

What would you do differently, given the opportunity to repeat the degree project?

Summary

In what way has the degree project contributed to satisfying the learning objectives of the study programme?

How has sustainability been addressed in your education?

If you have any suggestions about how the study programme can be improved, please describe these.

To what extent do you feel ready to embark on a career?

CONTEXUALIZED ROADMAP TO ADVANCING SUSTAINABILITY IN SCHOOL OF ELECTRICAL & ELECTRONIC ENGINEERING

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ABSTRACT

This paper highlights the need to deepen key sustainability competencies contextualized within domain-specific courses. It explores the integration of these competencies into the Diploma in Electrical and Electronics Engineering (DEEE) curriculum, leveraging the Common Core Curriculum (CCC) and the Conceive, Design, Implement, Operate (CDIO) framework already in place. The integration is guided by a flexible framework developed in Singapore Polytechnic (SP), which outlines eight key sustainability competencies: systems thinking, futures thinking, values thinking, strategic thinking, interpersonal, intrapersonal, implementation, and integrated problem-solving. This paper explains the work done, beginning with identifying the existing skills and gaps, followed by progressively introducing or enhancing these competencies within suitable domain-specific modules, aligned with the DEEE course structure, advancing from foundational to advanced levels. This paper demonstrates how these sustainability competencies are applied in practice, using a case study based on the CDIO project in a Year 2 module Microcontroller Applications (MAPP). First, it shares the results of a gap analysis on all Year 1 modules and how it can support learning MAPP. Next, it illustrates how the competencies are contextualized and applied throughout the CDIO project phases. It then outlines how the deepening of the key competencies can be achieved in Year 3 using a lifecycle approach for the Sustainable Energy Specialization track. This approach strengthens the course's alignment with sustainability education goals and demonstrates how the approach from SP, built on the CDIO framework, is used to deepen necessary sustainability competencies within a course.

KEYWORDS

Sustainable Development, Common Core, Key Sustainability Competencies, CDIO Syllabus & Standards 1- 12.

NOTE: Singapore Polytechnic uses the word 'courses' to describe its education 'programs'. A 'course' in the Diploma in Chemical Engineering consists of many subjects that are termed 'modules'; which in the universities' contexts are often called 'courses'. A teaching academic is known as a 'lecturer', which is often referred to a as 'faculty' in the universities.

FOUNDATION FOR SUSTAINABILITY IN SEEE DIPLOMA PROGRAMS

Since 2008, the School of Electrical and Electronics Engineering (SEEE) at Singapore Polytechnic (SP) has designed all its three-year diploma courses according to the CDIO (Conceive-Design-Implement-Operate) framework. Applying the CDIO approach has helped SEEE to blend technical expertise with practical skills, preparing students to handle, and manage real-world projects and products. On top of the technical skills, CDIO also has a wide range of non-technical qualities such as ethical responsibility, teamwork, lifelong learning that is vital for engineering professionals. With the integration of these qualities into the SEEE curriculum, SEEE graduates are equipped to become more holistic professionals who can adapt, collaborate, and contribute meaningfully to both industry and society.

Throughout the years, SEEE has regularly revise its curriculum using the CDIO framework to adhere to regulatory guidelines, and emerging industry trends, to ensure its relevance in this fast-changing world. One significant update was the introduction of the SP Common Core Curriculum (CCC). It consists of ten Common Core (CC) modules, focusing on both digital and human abilities contextualized using selected United Nations Sustainable Development Goals (UN SDGs) as learning contexts. It was first introduced in 2022 (Cheah et al., 2022) and became fully implemented across all SP diploma courses, including SEEE diploma programs in 2023. By taking these ten CC modules, SP students develop essential foundational skills and competencies. However, these are not sufficient for tackling today's complex sustainability challenges. For example, the lead author's experience on working on a corporate decarbonization project demonstrated that team members from diverse domains need a sufficient common understanding of sustainability concepts (e.g., greenhouse gas inventories, carbon emissions, and reporting standards) to effectively contribute and collaborate. However, addressing certain challenges, such as food waste management, often required specialized expertise, highlighting the importance of interdisciplinary knowledge and teamwork in tackling complex sustainability issues.

Cheah et al. (2025) suggested a generic approach for integrating key competencies in any SP courses based on the CDIO framework. Yang, Cheah & Wong (2025) provided broad guidance on how to operationalize the suggested approach by any program embarking on integrating sustainability mindset into the curriculum, taking into considerations the foundations laid by the CC modules (with the UNSDGs as learning context) to develop key sustainability competencies guided by the CDIO syllabus and disciplinary domain as the focus. This paper aims to focus on deepening the key sustainability competencies by contextualizing them using Diploma in Electrical and Electronics Engineering (DEEE) as the case study. This approach ensures that DEEE students are equipped with fundamental sustainability knowledge such as understanding UN SDGs, key competencies and domain specific expertise that develop the sustainability mindset that prepares them in addressing the complex sustainability challenges within their field in an effective way.

BRIEF DESCRIPTION OF SP APPROACH

To support SP's institutional goals of enhancing sustainability education, the framework developed by Cheah et al. (2025) allows each diploma course to integrate key sustainability competencies tailored to its specific context. Based on a comprehensive literature review and analysis of existing studies, including those by UNESCO (2017), the framework outline eight key sustainability competencies namely systems thinking, futures thinking, values thinking, strategic thinking, interpersonal, intrapersonal, implementation, and integrated problem-solving. The definitions for these competencies, taken from Redman & Wiek, (2021), are

provided in Table 1. In terms on terminology, it is noteworthy that anticipatory, normative, and collaborative competencies are same as futures thinking, values thinking and interpersonal competencies respectively. Also, intrapersonal competency which encompasses self-awareness, is also aligned with the UNESCO (2017) key sustainability competencies.

Table 1. Short definitions of the key competencies in sustainability, (Redman & Wiek, 2021).

Key Competencies	Definitions
System Thinking Competency	Ability to apply modeling and complex analytical approaches: 1) to analyze complex systems and sustainability problems across different domains (environmental, social, economic) and across different scales (local to global), including cascading effects, inertia, feedback loops, and other system dynamics; 2) to analyze the impacts of sustainability action plans (strategies) and interventions (how they change systems and problems).
Futures Thinking (Anticipatory) Competency	Ability to carry out or construct simulations, forecasts, scenarios, and visions: 1) to anticipate future states and dynamics of complex systems and sustainability problems; 2) to anticipate how sustainability action plans (strategies) might play out in the future (if implemented).
Values Thinking (Normative) Competency	Ability to identify, map, specify, negotiate, and apply sustainability values, principles, and goals: 1) to assess the sustainability of current and/or future states of complex systems; and 2) to construct sustainability visions for these systems; 3) to assess the sustainability of action plans (strategies) and interventions.
Strategic Competency	Ability to construct and test viable strategies (action plans) for interventions, transitions, and transformations toward sustainability.
Interpersonal (Collaborative) Competency	Ability 1) to collaborate successfully in inter-disciplinary and -professional teams; and 2) to involve diverse stakeholders, in meaningful and effective ways, in advancing sustainability transformations.
Intrapersonal Competency	Ability to avoid personal health challenges and burnout in advancing sustainability transformations through resilience-oriented self-care (awareness and self-regulation).
Implementation Competency	Ability to put sustainability strategies (action plans) into action, including implementation, adaptation, transfer and scaling, in effective and efficient ways.
Problem-solving Competency	Ability to apply collective problem-solving procedures to complex sustainability problems: 1) to develop viable sustainability strategies (action plans); and 2) successfully implement them, in collaborative and self-caring ways.

PROGRESSIVE INTEGRATION OF COMPETENCIES ACROSS THE CURRICULUM: SEEE APPROACH

In SEEE, all the three-year diploma courses are designed with a structured progression that guides students from foundational learning to specialized knowledge. Guided by SP's adoption of the CDIO framework, this structured approach uses CDIO integrated curriculum and ensures that students not only gain domain knowledge but also develop essential CDIO skills, practical engineering experience, and necessary attitudes to thrive in their chosen field. To provide students with the flexibility to personalize their learning journey, electives are offered starting from the second year. The curriculum consists of mandatory domain and CC modules, as well as electives, with mandatory courses represented by pin symbols and electives by circle symbols, as shown in Figure 1.

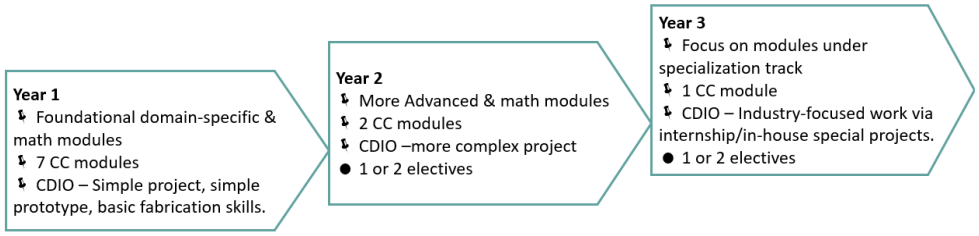


Figure 1. How domain-related skills, core competencies and CDIO skills are progressively built across 3 Years Diplomas in SEEE.

The ten CC modules are strategically introduced across all three years, catering to the specific needs of each diploma, using selected UN SDGs as learning context and fostering a well-rounded, gradual development. All the diploma courses in SEEE are organized into Year 1, Year 2, and Year 3 as follows:

Year 1: Building Foundational Competencies in SEEE

In Year 1, all SEEE students complete modules that establish foundational knowledge and competencies through the mandatory CC modules, mathematics, and introductory domain-specific modules. Among these, students undertake seven CC modules (as outlined in the final row in Table 3) that emphasize transferable skills with selected UN SDGs as the learning context. For example, in the CC module: *Thinking Critically about the UN SDGs (TCU)*, students are introduced to the SDGs and develop critical skills in questioning, evaluating diverse perspectives, and assessing information credibility. Additionally, in project-based modules like *Introduction to Programming (IEP)*, students use Arduino to create prototypes with simple input/output devices. Similarly, in *Introduction to Engineering Design (IED)*, students apply theoretical concepts from foundational modules such as *Principles of Electrical & Electronic Engineering* and *Digital Electronics* in their project work, gaining basic fabrication skills through tasks such as simple circuit construction and 3D printing.

Year 2: Deepening Competencies, CDIO Skills and Technical in DEEE

In Year 2, all SEEE students will take another two CC modules namely the *Artificial Intelligence and its impact (AII)* and *Sustainable Innovation Project (SIP)*. Notably in *SIP*, students collaborate in multidisciplinary teams across SP to address sustainability-oriented challenges, strengthening their interpersonal competency and CDIO skills, particularly in design thinking. They will also progress to more advanced, domain-specific modules such as *Circuit Theory and Analysis*, tailored to their respective course tracks. In DEEE, modules like *Microcontroller Applications (MAPP)* further enhance students' CDIO abilities and integrated problem-solving competencies, as students are required to synthesize knowledge from various modules and apply these skills, preparing them for increasingly complex projects (Chong et al., 2010; 2011). More advanced skills and attitudes develop include analytic thinking, logical thinking and problem-solving skills. Students also have the flexibility to take one or two electives, allowing them to tailor their learning experience, starting from Year 2.

Year 3: Industry internship and Specialization Tracks in DEEE

In Year 3, all SEEE students dedicate one semester to industry internships or in-house special projects, providing opportunities to apply the competencies gained during their first two years in real-world contexts. These experiences expose students to complex, unpredictable challenges, fostering critical thinking and adaptability beyond the classroom. For DEEE students, the other semester is spent completing the final CC module, *Personal Branding and Career Agility (PBCA),* alongside elective modules, and specialized coursework under their chosen specialization tracks, as illustrated in Table 2.

These pathways allow students to deepen their expertise in specific fields. For example, students pursuing the *Rapid Transit Technology* track focus on advancing their expertise in technologies related to the mass urban transportation adopted locally, while those in the *Sustainable Energy* track focus on technologies such as solar photovoltaic system, electric vehicles, energy storage, and smart sustainable infrastructure, aligning with Singapore's initiatives to promote sustainable development within the energy sector. At present, there is no systematic integration of sustainability competencies across all Year 3 specialization tracks.

However, we noted that specific modules within these tracks present promising opportunities to embed relevant sustainability topics. Building on the foundation that has been established, this paper focuses on enhancing the integration of sustainability competencies in selected Year 2 modules by building on the competencies developed in Year 1. It then extends to Year 3, focusing on the Specialization Track: *Sustainable Energy*. The goal is to deepen the identified key competencies, contextualized to the specific modules, while simultaneously advancing their technical knowledge and skills.

Table 2. Overview of the Seven Year 3 Specialization tracks and Modules offered in DEEE.

Track	Biomedical Engineering	Communication Engineering	Microelectronics	Power Engineering	Rapid Transit Technology	Robotics & Control	Sustainable Energy
Modules	Anatomy & Physiology	Digital Signal Processing	IC Testing	Power Electronics & Drives	Rapid Transit Signalling System	Systems & Control	Photovoltaic System Design
	Biomedical Instrumentation Design & Applications	Principles of Communication	Quality & Reliability	Power Transmission & Distribution	Rapid Transit System	Robotics Technology	Smart Grid & Building Energy Management
	Biomedical Equipment & Practices	Satellite & Optical Communication	IC Design	Power System Analysis	Smart Sensors & Actuators	Smart Sensors & Actuators	Electric Vehicle Technology
	Robotics Technology	Wireless Technology Applications	Wafer Fabrication Technology	Smart Grid & Energy Storage	Principles of Communication	Digital Manufacturing Technology	Hydrogen, Fuel Cell Technology & Energy Storage

THE YEAR 1 COMPETENCY LANDSCAPE: ACHIEVEMENTS AND NEXT STEPS

To understand the current integration of sustainability competencies within SEEE curriculum, a comprehensive review of Year 1 modules was conducted. All the learning activities in Year 1 modules were reviewed and mapped to the relevant key sustainability competencies, aligning with the corresponding sections of the CDIO Syllabus 3.0 and the framework developed by Cheah et al (2025). The results were then tabulated in Table 3, listing the key sustainability competencies, the corresponding CDIO Syllabus sections, and representative example(s) of relevant learning activities.

From our review, we found that values thinking, strategic thinking, systems thinking, and integrated problem-solving are introduced at a foundational level in Year 1. Though values thinking is essential, it is more prominent in broader societal contexts requiring ethical decision-making (Wiek et al., 2011) and in specialized domains. For example, in field of agriculture, it is important to balance the need for food production with ethical considerations related to the environmental and social impacts of agricultural practices, such as land use and pesticide usage. For SEEE, as the focus remains on developing technical problem-solving and systemic innovation, values thinking will be tailored to each specialization track to prepare students to navigate ethical dilemmas within their chosen track.

Strategic competency is introduced via the CC module: *Problem Solving with Creative & Computational Thinking (PSCCT)* where students develop creative and computational thinking skills. In *PSCCT*, assessments includes quizzes and a final team presentation, evaluated using a guided rubric to ensure consistency. The skills learned in this module can then be applied to other relevant modules, further reinforcing students' ability to think strategically in different contexts. This competency also includes ability to prepare action plans for interventions, which students can develop via creating project schedules, responding to unforeseen challenges, and managing project execution in project-based modules. However,

as this development is not fully captured, more explicit measures are needed to support its development.

Systems thinking competency is perceived to be a highly important competency in engineering as it enables students to analyse interconnected components of complex systems and address challenges holistically. For SEEE students, this skill is particularly vital in areas such as energy systems where technical, environmental, and societal factors intersect. As systems thinking can only be effectively developed as students' technical knowledge progresses, higher order applications are more effectively developed in Year 2 and 3 when the students gain advanced knowledge and engage in more complex projects.

Table 3: Key Sustainability Competencies, the corresponding CDIO Syllabus Covered in Year 1 SEEE Modules

Key Sustainability Competencies	CDIO Syllabus	Year 1 Modules and Representative activities(s)
System Thinking Competency	(2.3.1), (2.3.2)	CC modules: **PSCCT & DF** Domain-specific modules: **IEP and IED** e.g in PSCCT, students identify and analyse problems related to the UN SDGs, understanding their interconnectedness with broader systems. They apply problem identification and the 4 pillars of computational thinking to devise solutions that consider systemic impacts in PSCCT.
Futures Thinking (Anticipatory) Competency	To be developed	
Values Thinking (Normative) Competency	(2.5.1),(2.5.6)	CC module: **TCU, CDA** e.g Students engage with value-based judgments, considering ethical implications and fairness when forming arguments on current sustainability issues.
Strategic Competency	(2.4.4), (2.4.8)	CC modules: **EWW, DCI, PCDF & PSCCT** Domain-specific modules: **IEP and IED** e.g In PSCCT, Students combine creative and computational thinking, utilizing tools such as AI to tackle complex sustainability problems, ensuring their solutions are innovative and technologically feasible.
Interpersonal (Collaborative) Competency	(3.1.1), (3.2.1)- (3.2.6) (3.2.9)	CC modules: **TCU, CDA, DCI, PSCCT, DF & PCDF** Domain-specific modules: **IEP and IED** e.g In CDA, students learn to work effectively as team members, using the Comprehensive Assessment of Team Member Effectiveness (CATME) model to foster successful teamwork, role definition, and effective collaboration in both online and offline settings.
Intrapersonal Competency	(2.4.5), (2.4.6) (2.4.7), (4.1.1), (4.1.5), (4.1.6)	Self-directed learning (SDL) is promoted through asynchronous lectures, online tutorials, and e-practical lessons, enhancing flexibility and self-awareness across the SEEE curriculum. Problem-based modules in Years 1 and 2 engage students with UNSDG-related issues, fostering an understanding of engineering's societal and environmental impact.
Implementation Competency	(2.4.3), (2.4.8)	All relevant modules as students need to adapt accordingly, manage their time and resources while handling multiple assignments and projects concurrently.
Problem-solving Competency	(4.3) - (4.6)	All domain specific project-based modules: **IEP and IED** (Year 1) **& MAPP and PLC** (Year 2) Students work on projects, integrating relevant CDIO skills, competencies, technical knowledge from simple projects in year 1 to more advanced projects in year 2.
Module Abbreviations for CC modules: CDA -Collaboration in the Digital Age, DCI-Digital Communication for Impact, DF-Data Fluency, EWW-Effective Writing for the Workplace, PCDF-Persuasive Communication with Data Storytelling, PSCCT-Problem Solving with Creative & Computational Thinking, TCU-Thinking Critically about the UN SDGs. Domain-specific modules: IED-Introduction to Engineering & Design, IEP-Introduction to Programming, MAPP-Microcontroller Applications, PLC- Programmable Logic Controller		

Intrapersonal competency has been progressing well, particularly following the introduction of asynchronous lectures with weekly quizzes and e-practical lessons during the COVID-19 pandemic. These methods, leveraging technology and real-time feedback, have sustained student engagement and encourage adaptability and self-reflection (Toh et al., 2021).

Additionally, students frequently work on projects related to sustainability challenges, which encouraged them to reflect on their roles and responsibilities as engineers. This approach fosters self-awareness and adaptability, aligning with various sections of the CDIO Syllabus, including (2.4.6), (2.4.5), (4.1.1), and (4.1.2). As such this competency is currently under the development stage.

Interpersonal competency is well embedded across the SEEE curriculum through abundant teamwork opportunities, aligning closely with CDIO Syllabus Section 3.0: Interpersonal Skills, Collaboration, Teamwork, and Communication (Crawley et al., 2014). Furthermore, SP adoption of Team Based Learning (TBL) further enhances this competency by fostering communication, accountability, and self-awareness, supported by self- and peer-assessments (Pee et al., 2024). Then in year 2, all the SEEE students deepen this competency by working in multidisciplinary teams on sustainability-related challenges in the CC module: *SIP*, enabling them to apply collaborative skills in addressing real-world issues.

Currently, the only gap in SEEE curriculum is futures thinking competency. This competency is important as it enables students to plan for future challenges in areas like energy systems and smart technology, consider the long-term effects of their designs, and create innovative sustainability-oriented solutions that support sustainability. According to Wiek et. (2011), a staged development approach beginning with novice-level exposure is effective. Therefore, Year 1 modules like *IED* or *IEP* will be explored to introduce this competency, laying the foundation for its deeper development as the student progress.

Lastly, for implementation and integrated problem-solving competency, all SEEE students get to progressively develop these competencies through hands-on CDIO projects (Standard 5) in project-based modules such as *IEP* and *IED*. Starting with simpler projects in Year 1, students integrate foundational CDIO skills, sustainability competencies, and technical knowledge. These projects are assessed using structured rubrics in domain-specific modules, ensuring consistency in evaluating students' technical knowledge, project deliverables, and design processes. As students advance to Year 2, they tackle more complex projects that require deeper integration of advanced competencies, preparing them for real-world problem-solving challenges in their fields. Thus, these two competencies are considered adequately addressed through the progression from simple projects in Year 1 to more advanced applications in later years.

BRIDGING GAPS AND STRENGTHENING INTEGRATION IN DEEE CURRICULUM

With foundational sustainability competencies such as values thinking, strategic and systems thinking introduced in Year 1, and with competencies such as interpersonal, intrapersonal, implementation and integrated problem-solving competencies that are in good progression in year 2 and/or Year 3, the next step is to address gaps in Year 1 and strengthen specific targeted competencies in Year 2 as outlined in Table 4.

In Year 3, the focus will shift to deepening relevant competencies based on the chosen specialization track, which will be detailed in the next section. To begin, the futures thinking competency will be introduced in the Year 1 *IED* module during the conceive phase of the CDIO project. In this phase, students will project near-future scenarios, such as increasing flight turbulence, to frame the problem statements for their project, laying a foundation for deeper development and application of this competency in subsequent years. In Years 2, the focus shifts to deepening the futures thinking and system thinking competencies within domain-specific contexts. To achieve this, a review of the corresponding CDIO syllabus and

the DEEE curriculum was conducted to identify suitable modules and opportunities for integrating these competencies, ensuring that students build upon their Year 1 competencies and develop them in realistic, domain-specific scenarios. For example, in Year 2, system thinking is enhanced in the *MAPP* module, where students identify key stakeholders and evaluate the environmental, cost and social impacts in their microcontroller-based project proposals. Similarly, futures thinking is further enhanced in the *PLC* module, where students first work on a problem with a traditional carpark system, then transition to future carparks, both constructed using Digital Twin technology. Such a shift encourages students to explore how future technologies and evolving societal needs could transform the design and function of carparks and, more importantly, allows them to experience how solutions must adapt to dynamic and uncertain environments, learning to anticipate and respond to change, an essential skill for tackling sustainability challenges.

Table 4: Mapping Sustainability Competencies to Domain-Specific Modules for Year 1 and 2 in DEEE Curriculum

Year	Targeted Competency	CDIO Syllabus	Module(s) & Potential learning activities
1	Futures Thinking (Anticipatory) Competency	(4.1.6)	Module: **IED** Introduce the concept of futures thinking competency. During the conceive phase of the project, students get to envision short-term futures scenarios related to their project.
2	Futures Thinking (Anticipatory) Competency	(4.1.6), (2.5.1)	Module: **MAPP** In the conceive phase of the CDIO project, students develop future scenarios to anticipate how their identified sustainability might evolve. Module: **PLC** Students can explore both traditional and future carparks using digital twin technology in the lab to understand how current systems can evolve and how specific solutions to facilitate the transition is needed when working on the solutions.
	System Thinking Competency	(2.3.1) (2.3.2)	Module: **MAPP** In the conceive phase of the CDIO project, students need to identify key stakeholders and evaluate the environmental, cost and social impacts in their microcontroller-based project proposals. Module: **PLC** In the practical lab, students can work on a PLC program e.g to control the lighting system of a building, adjusting light levels based on occupancy or time of day and allow them to analyse the trade-offs between energy savings and lighting quality.
	Strategic and Futures Thinking Competency	(2.4.8) (4.1.6)	Module: **MAPP** Students will work in teams to create a Gantt Chart, develop a project timeline, list tasks, allocate resources, use the chart to adjust plans based on changing conditions. They are also encourage to reflect on past decision-making they made in Year 1, participate in scenario-based exercises to simulate challenges when creating the project schedule.

CASE STUDY: SUSTAINABILITY COMPETENCIES IN ACTION VIA A CDIO PROJECT

Sustainability challenges are inherently complex and problem-based, requiring value-driven, holistic, and practical solutions (Wiek et al., 2011). Prior work has established a structured developmental approach, progressing from foundational competencies to higher-order ones like integrated problem-solving. Using the project in *MAPP* as the case study, this section demonstrates how these progressively planned competencies are developed and applied in a typical CDIO project in SEEE as illustrated in Figure 2 to showcase the roadmap's goals in practice.

Preparation Work and Team Formation

Before working on the CDIO projects, the students first begin by acquiring or reconnecting with relevant theories and practical skills from prior modules. Teams of three or four students are then formed, allowing them to apply teamwork principles learned in the CC module, *CDA*, to develop the various dimensions of interpersonal competency while working together throughout the project.

Conceive and Design Phases

In the Conceive phase, each team identifies a sustainability-related problem as they apply critical thinking skills (2.4.5) to effectively analyze and define the issue. This is followed by constructing future scenarios (4.1.6) where students are encouraged to envision different future possibilities to identify potential challenges and opportunities based on current trends, and emerging technologies.

During the problem framing process, students reflect on the roles and responsibilities of engineers (4.1.1). They are prompted to consider how their work as engineers can influence society, the environment, and the economy. This reflection helps them understand the ethical, social, and environmental responsibilities that come with engineering decisions. Students are encouraged to recognize the importance of designing solutions that are not only technically sound but also socially equitable, environmentally sustainable, and aligned with ethical principles (3.1.1), (3.1.2). This stage ensures that students appreciate the broader impact of engineering and the need for responsible, values-driven decision-making throughout the project. As the team brainstorm solutions, they are encouraged to apply the creative thinking (2.4.4) and/or designing thinking tools they have learnt in *PSCCT* and in *SIP* respectively. These are strategic thinking competency is also further enhanced by staying informed about advancements in the engineering field (2.5.4) and engaging in inquiry, active listening, and dialogue with their teammates, and considering the environmental, social, and economic impacts of the potential target stakeholders (3.2.7).

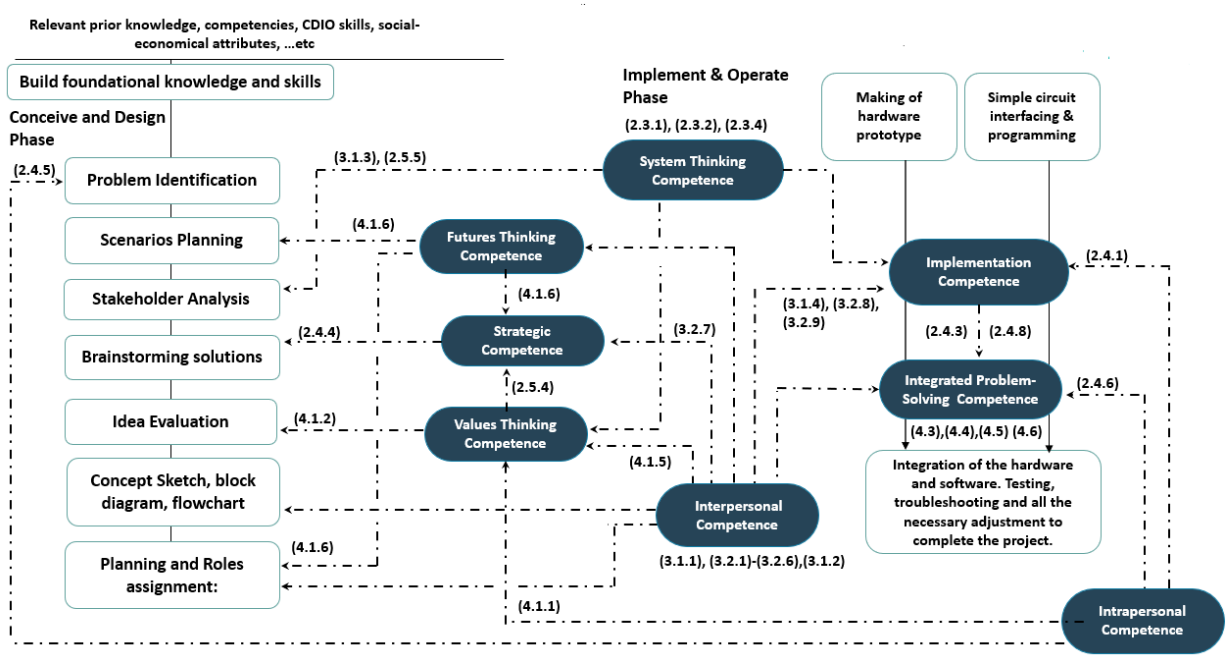


Figure 2. Integrating CDIO Phases with Sustainability Key Competencies in a typical project-based module: A case study of a project in MAPP.

As teams evaluate their final ideas, they apply systems thinking to ensure a holistic perspective. This includes considering the social, economic, and environmental implications, the feasibility of their proposed solutions, and the broader impact of their engineering work on society and the environment (3.1.3). Transitioning to the Design phase, teams then create detailed sketches, diagrams, and flowcharts outlining their proposed solutions and plan the project schedule, identifying and organizing tasks. Lecturers provide feedback during this phase, encouraging students to address potential challenges proactively, which further strengthens their futures thinking (4.1.6). Additionally, students develop essential time and resource management skills (2.4.8) using tools like Gantt charts, ensuring a structured approach to the implementation of their solutions.

Implement and Operate Phases

During the implement and operate phases, students apply technical knowledge from MAPP and other relevant modules to build and test their solutions, troubleshooting and iterating till they get it right. These processes help to emphasize adaptability, resilience, and perseverance. Teams are also likely to refine their projects in response to challenges, applying systems thinking and problem-solving competencies (2.4.1), (2.4.3) or even take responsibility for self-improvement to address weaknesses to contribute to the project effectively (2.4.6). For the project to work, systems thinking (2.3.1) – (2.3.4) plays a crucial role. Students need to understand the interrelationships and dynamics between the various components of their project, especially when it comes to integrating hardware and software. They must consider how each part functions individually and within the system. This requires a holistic perspective, where students analyse the functional and behavioural properties of the system, identify feedback loops, and foresee potential unintended consequences. By applying systems thinking, students ensure their solutions are not only technically viable but also sustainable and adaptable over time. Lastly, students need to integrate all the necessary key competencies, knowledge, and skills, showcasing their integrated problem-solving competency to complete the project.

This structured, iterative approach to project work allows students to progressively develop their key competencies while tackling increasingly complex challenges. In each phase of the CDIO process, Conceive, Design, Implement, and Operate, students engage in activities that strengthen their problem-solving capabilities and enhance the relevant key competencies. Each phase not only builds on the competencies developed in the previous phase but also deepens the application of those competencies. For example, students apply systems thinking during the Design phase, and must apply it again in the Implement and Operate phases so that the whole system can function as intended. By sequencing the key competencies this way, this approach fosters both technical expertise and the necessary competencies, necessary for future engineers to navigate the complexities of sustainability.

EMBEDDING SYSTEMS AND VALUES THINKING IN THIRD-YEAR SPECIALIZATION MODULES

Building on the foundation established in the first two years, the focus in Year 3 shifts to developing relevant competencies within each specialization track. For the "Sustainable Energy" specialization track, the focus is on developing advanced competencies in particularly systems thinking and values thinking competencies. Life Cycle Thinking (LCT) is introduced to enable students to understand the environmental, social, and economic impacts associated with each stage of a product or system's life cycle, from raw material extraction to end-of-life disposal or recycling (UNEP, 2005). This approach aligns with Wiek et al. (2011) systems

thinking competency, helping students anticipate and mitigate sustainability challenges in their future careers.

In this specialization track, students will focus only on a single phase of the life cycle that corresponds to their modules, as shown in Table 5 to ensure learning remains impactful and manageable. For example, in the Solar Photovoltaic System Design module, students focus on the disposal and recycling phase of solar panels, gaining understanding on challenges like material separation and recycling efficiency. They then evaluate how design decisions, such as using recyclable materials or ensuring proper installation, can reduce environmental impacts at the end-of-life stage.

To support the deepening of system and values thinking competencies, learning activities focus on building an understanding the interconnectedness of life cycle stages and the trade-offs involved in decision-making. Students analyze synergies and conflicts between environmental, social, and economic considerations, preparing them to make informed, strategic decisions (2.3.4). Ethical responsibility is another core focus, encouraging students to reflect on societal impacts, analyze ethical dilemmas by weighing risks and benefits (2.4.1), and develop accountability in their professional contributions (2.4.6), (4.1.2). Through this, they cultivate the ability to support their decisions with sound reasoning (2.5.1) and adopt a proactive mindset to contribute to sustainable futures at both local and global levels (2.5.3).

Table 5. Focused Life Cycle Phases and Corresponding Learning Activities under the Specialization Track - *Sustainable Energy.*

Modules	Life Cycle Phase(s)	Targeted Competencies	Potential learning activities
Photovoltaic System Design	Recycling/ Disposal phase	System Thinking Competency (2.3.2), (2.3.4),(4.1.7) Futures Thinking (Anticipatory) Competency (4.1.6), (2.5.1) Values Thinking (Normative) Competency (4.1.5) Collaboration competency (3.1.1) -(3.1.4), (3.2)	Students explore the challenges associated with solar panel disposal/recycling, such as waste management, material recovery, and reflect on how the design decisions can impact the disposal/recycling phases.
Smart Grid & Building Energy Management	Use and maintenance phase		Students were given building data that in order to analyse the energy use patterns and proposing strategies to optimize energy performance, with the focus to reduce lifecycle energy savings.
Electric Vehicle Technology	Use and maintenance phase		Students analyze the GHG emissions of electric vehicles (EVs) under different electricity grid emission factors to understand how their carbon footprint is influenced by the energy mix. They will also evaluate the trade-offs between adopting EVs and internal combustion engine (ICE) vehicles. This activity highlights the interconnectedness of transportation, energy systems, and the challenges associated with encouraging EV adoption.
Hydrogen, Fuel Cell Technology & Energy Storage	Production phase		Students evaluate the carbon emissions of different hydrogen production methods such as grey, blue and green hydrogen. They then compare the lifecycle environmental impacts of hydrogen production with and without carbon capture technologies.

Life cycle considerations are embedded throughout the specialization track, helping students appreciate decisions made in any stages of the life cycle, such as material selection and design processes, can shape outcomes at later stages like maintenance and disposal (4.1.6), (4.4.1). By engaging with these complexities, students gain a holistic perspective on the impacts of engineering, fostering an understanding of how their work influences environmental, social, knowledge, and economic systems (4.1.2).

Teamwork and communication are central to all activities, as students collaborate in groups to articulate their ideas, share perspectives, and engage in structured discussions. Through these discussions, students develop a comprehensive understanding of sustainability challenges and learn to integrate diverse viewpoints and life cycle considerations into their roles and decisions, (3.3.1) – (3.3.4), (3.2). These shared experiences align with the learning objectives within the specialization track, helping students grasp the broader impacts of their actions and laying the foundation for responsible engineering practices that contribute meaningfully to global sustainability efforts.

CONCLUSION

This paper highlights the importance of deepening sustainability competencies within domain-specific diploma courses, starting with foundational competencies in Year 1. Drawing on Cheah et al. (2025) flexible framework, the paper explores their integration into the DEEE curriculum. A crucial first step is conducting a gap analysis, which identifies opportunities for embedding sustainability competencies while acknowledging that learning contexts differ across disciplines. As such, the integration of sustainability competencies may vary, with certain competencies requiring deeper focus depending on the specific course and its relevance. As illustrated in the paper, a complete review of the current Year 1 SEEE curriculum was carried out to identify gaps and opportunities for further development, particularly in futures thinking and systems thinking. Based on this analysis, the paper outlines potential learning activities and proposes modules to deepen these competencies across the DEEE course. A case study from the MAPP module in Year 2 illustrates how these competencies can be progressively developed across the CDIO project phases. To ensure continuous competency development, the focus in Year 3 shifts toward deepening systems thinking and values thinking within the Sustainable Energy Specialization track. While it is too early to conclude that students are fully equipped to tackle sustainability-related projects, the findings suggest that the proposed activities progressively build students' key sustainability competencies, laying the groundwork for future applications. The paper concludes that this adaptable approach allows for meaningful integration across various diploma courses without requiring major structural changes, supporting long-term, sustainable curriculum development.

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BIOGRAPHICAL INFORMATION

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ACTIVE LEARNING COMMUNITY FOR PROFESSIONAL DEVELOPMENT: A CDIO STANDARD 10 IMPLEMENTATION MODEL

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School of Architecture and the Built Environment, Singapore Polytechnic

ABSTRACT

This study offers a qualitative investigation and implementation of Faculty Learning Communities (FLC) as enabler to support the operationalization of Conceive, Design, Implement and Operate (CDIO) Standard 10 which emphasizes the improvement of faculty teaching competence at the School of Architecture and the Built Environment (ABE) and the Singapore Maritime Academy (SMA) at the Singapore Polytechnic (SP). This implementation of the FLC approach, facilitated by a group of Teaching and Learning Mentors and Specialists (TLMS), takes the form of an Active Learning Community (ALC) aimed at fostering collaboration and professional development among teaching staff with activities like symposiums, monthly sharing sessions, book studies and curated hands-on workshops. The monthly ALC sessions cumulate as a large-scale 'Active Learning Symposium' (ALS) for staff from two schools. The 2024 ALS highlighted novel pedagogical strategies and assist academics in contextualising them into their teaching practices, highlighting the interdependent relationships of various Teaching and Learning (T&L) initiatives introduced over the years. Participants' reflections emerged as crucial themes related to pedagogy, teaching practices, and feasibility of pedagogical adaptation facilitated by CDIO standards 8 and 10 during the 2024 ALS. Participants also expressed cautious optimism, appreciation, commitment to development, and encouragement for data-driven initiatives, further reinforcing the potential of organising future large-scale symposiums with a strong focus on contextualising CDIO Framework in teaching strategies and curriculum development. The findings of this study highlighted the importance of bridging educational gaps and enhancing teaching effectiveness while ensuring congruence with the outcome-based education through the operationalisation of CDIO frameworks. This paper introduces a holistic approach and provides insights into implementing CDIO Standard 10 by practicing CDIO Standard 8 as a teaching method. It emphasizes how this collaborative learning method, emphasizing its potential to catalyse future transformative CDIO FLC in higher education teaching and learning.

KEYWORDS

Learning community, professional development, transformation, CDIO Standards 8 and 10.

BACKGROUND

In response to the challenge of enhancing teaching staff competence as per CDIO Standard 10, Soo-Ng (2020) from the School of Architecture and the Built Environment (ABE) at Singapore Polytechnic (SP) implemented a novel professional development model centered around the concept of a Learning Community (LC). This initiative evolved from the Action Research (AR) Group, created in 2009 to address ineffective lecture-based learning. However, the AR Group's task force approach lacked sufficient collaborative learning and ongoing support, leading to its reform. The transition to the Active Learning Community (ALC) was driven by the need for a more supportive, collegial environment, drawing on the principles of communities of practice (Wenger, 2002). By 2011, the ALC was firmly established, promoting active learning, out-of-class activities, and assessments. It supported professional development through book studies, reflective practices, symposiums, and peer-sharing sessions. This paper extends the ALC model's implementation, aiming to expand its principles to a broader academic context. The next phase focuses on operationalizing the ALC model, addressing challenges, and sharing experiences to foster a culture of continuous improvement and collaborative learning for both staff and students.

INTRODUCTION

Faculty Learning Communities (FLCs) stem from the LC model, adapting its collaborative framework to focus on teaching staff development (Richlin & Cox, 2004). Many are familiar with FLCs, as they are commonly used in institutions across the USA. They consist of cross-disciplinary academics who engage in long-term, frequent, and informal sharing activities. These communities aim to contextualize and integrate novel pedagogical approaches, foster professional growth, encourage pedagogical experimentation, and build a supportive academic community, addressing the complexities of modern education. In our context, we have named our FLC the Active Learning Community (ALC). From this point forward, the term ALC will be used in place of FLC.

Clavert et al. (2015) reported that traditional divisions between academic disciplines and different signature pedagogies can hinder the development and participation in ALCs. This is because these divisions often lead to differences in teaching approaches and objectives, creating potential misalignment between the goals of the disciplines and the collaborative goals of ALCs. Moreover, teaching staff with less influence within the academic hierarchy lack the authority and legitimacy to build a pedagogical research community (Zeng & Fickel, 2021). In a setting where teaching loads are growing and faculty members are naturally focused on research in within their domains, Chang (2017) advocated that the academics' participation in (pedagogical) learning communities can play a significant role in providing support to busy academics towards the adoption of emerging state-of-the-art pedagogical innovation.

This study discusses the impact and implications of participants' learning reflections and sentiments from the 2024 Active Learning Symposium (ALS) as reflective themes related to pedagogy, teaching practices, and its feasibility emerged. With the same dataset, participants' surfaced sentiments revolved around themes of cautious optimism, appreciation and gratitude, and commitment to developing students' soft skills through mediating disagreements and propensities towards data-driven pedagogical approaches. Although the trajectory of this pilot ALC did not explicitly propagate faculties' competencies in deploying CDIO standards, the encouraging findings of this pilot underscored the potential of organising future large-scale, cross ALC events in bridging educational gaps, enhancing teaching quality, and inducing academics to align their teaching practices with CDIO practices. Hence, this

study examined reflections and sentiments from large-scale ALC participants. The findings will guide future planning strategies to operationalise CDIO Standard 10, which focuses on enhancing faculty teaching competence. To support this, the study also explores how CDIO Standard 8, centered on active learning, can be adapted for faculty professional development in future CDIO ALC.

Active Learning Community (ALC) as an enabler of CDIO Standard 10

As faculty members aim to be proficient in using the CDIO approach to help students actively build knowledge, skills and attitudes, ALC is potential enabler of CDIO Standard 10 Enhancing Faculty Teaching Competence. Despite its potential in advancing pedagogical practices, CDIO Standard 10 is arguably the most overlooked, underdeveloped, and least documented (Edström, 2012). Cheah and Lee (2015) explicitly emphasised the vital role of ALC in maintaining CDIO Competencies with a mentoring framework as a response to the lack of emphasis given to faculty members' professional development. Thomson and Clark (2018) equally stressed the need to shift towards an evidence-based approach to Standard 10 that accentuates the importance of knowledge sharing in community settings as a gap that still needs to be addressed. Such trajectories have further reinforced the urgencies of harnessing ALC in facilitating pedagogical advancements.

ALC predicates on the works of John Dewey and Alexander Meiklejohn, whom both advocated for shared, practical learning. Their ideas have been widely adopted since the 1980s (Sicat et al., 2014). ALC emphasises and supports the institution's objective of enhancing the faculty's development of pedagogical competencies in achieving desired educational objectives (Reznik & Vdovina, 2018). Cox (2004) elucidated that ALC often consists of six to fifteen cross-disciplinary faculty members embarking on long-term and frequent informal sharing, activities to promote learning, development, teaching scholarships, and community building. These pedagogical learning communities provide a platform for faculty members to exchange ideas, engage in peer consultation and share best teaching practices, potentially broadening their impact. Furthermore, Pstross et al. (2017) elucidated that ALC's 'transformative moments' could serve as platforms for individuals to engage in continuous learning throughout their lives. Transformative learning utilises previous understanding and knowledge to create a fresh or updated interpretation of one's experiences in influencing future decisions and actions (Mezirow, 1996). Pstross et al. (2017) highlighted that the potential relationships between community building and lifelong learning experiences helps address the challenges posed by continuous societal changes through cycles of theory-building and reflective practices.

Experiential and Active Learning Methods: Operationalising CDIO Standard 8 To Support Standard 10

Experiential learning in the CDIO Framework is a student-centered, hands-on approach that promotes active participation, problem-solving, and the practical application of knowledge (Crawley, Malmqvist, & Östlund, 2014). It is guided through the stages of conceiving, designing, implementing, and operating solutions, helping students develop both technical and soft skills such as teamwork and communication. This complements CDIO Standard 8, which emphasizes engaging students in active thinking and problem-solving. The coherent integration of CDIO Standard 8 with Standard 10 is beneficial: educators are more likely to use active learning techniques after experiencing them in the collaborative and dialogical environment of the ALC workshops.

The call to evaluate faculty pedagogical approaches to enhance students' learning experiences through active learning has become increasingly important. Active learning

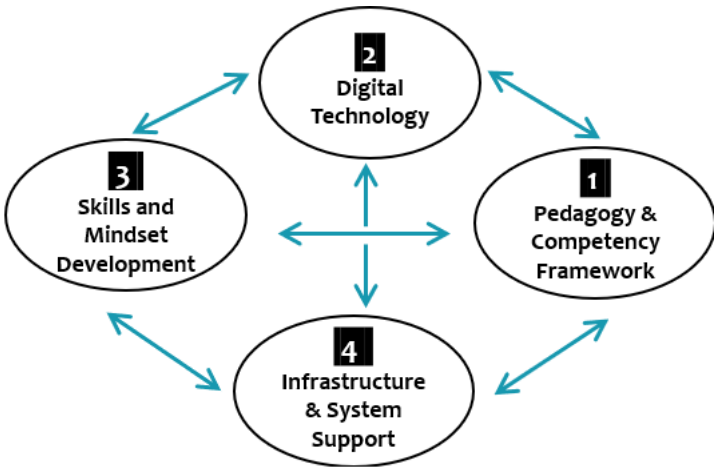
engages students in meaningful, hands-on learning rather than passive observation (Prince, 2004), immersing them actively in the process. Unlike traditional pedagogical models that stress passive memorization with teachers as sole authorities, Active Learning enhances teaching effectiveness, comprehension, engagement, and performance across disciplines, fostering a dynamic and interactive classroom environment (Coorey, 2016; Armbruster et al., 2009). Faculty members were encouraged to infuse interactive teaching/facilitation methods such as group discussions, problem-solving activities and hands-on exercises to foster deeper comprehension and critical thinking skills.

PROPOSED IMPLEMENTATION MODEL

Since 2011, ABE's Learning Mentors and Specialists (TLMS) have organized monthly ALC sessions for faculty. In 2022, SMA's TLMS also joined the monthly ALC session. These informal sessions foster collaboration and professional development through knowledge and pedagogical sharing, best practices, book studies, and tailored hands-on workshops. Beyond mere knowledge dissemination, the ALC focuses on contextualizing the institution's various educational initiatives. The sessions aim to enhance their teaching competence in designing, delivering, and improving curriculum courses by engaging faculty in hands-on activities grounded in Active Learning principles. ALCs' collaborative climate mirrored the ideas of a Community of Practice, with members engaging in shared learning and professional growth. As ALCs gain popularity, institutions should invest in faculty development and understand their experiences to ensure effectiveness (Stevenson et al., 2005).

ALC Symposium

At the conclusion of the academic year, the school of ABE and SMA will traditionally hold an Active Learning Symposium. The yearly symposium, echoing the monthly ALC sessions since 2011, serves as a reflective year-end event to share teaching initiatives and foster faculty collegiality. Specifically, the 2024 ALC symposium was designed to bridge the gap between the institution's seemingly 'disparate' educational initiatives (Figure 1a) and align them with the CDIO standards (Figure 1b).



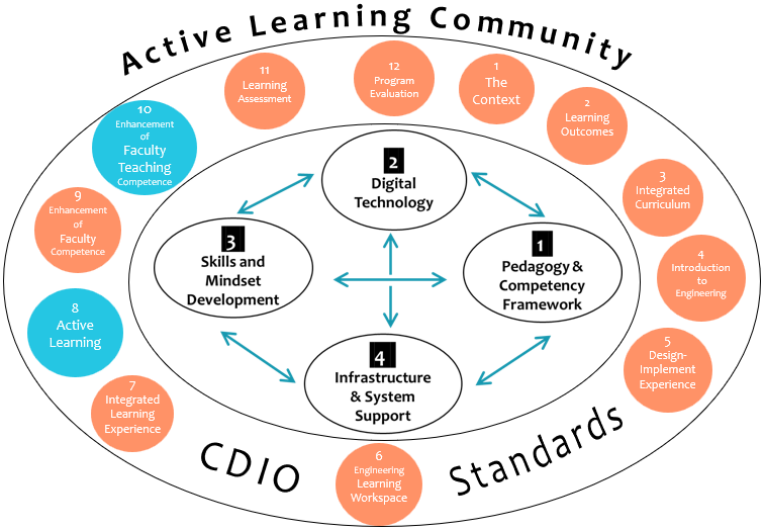
1. Pedagogy & Competency Framework
   - Analytics in Education (AiE)
   - Digital-to-the-Core (DTTC) Lecturer
   - Pedagogy for the Profession (P4P)
   - Data-Enabled Flipped Learning (DEFL)
   - Asynchronous Learning
   - Team Based Learning (TBL)
   - Differentiated Learning
   - CDIO

2. Digital Technologies
   - Generative AI (GenAI)
   - Industry Internet of Things (IIOT)
   - AR/VR/MR

3. Skills and Mindset Development
   - Teamwork Measurement (TM)
   - Self-Directed Learning (SDL)

4. Infrastructure & System Support
   - Learning Management System (LMS)
   - Classroom-of-the-Future (CotF)
   - Video Content Management System (VCMS)

Figure 1a. Educational Initiatives by the Institution.



Explanation:

This figure illustrates our cores and supporting interconnected T&L initiatives, driven by the CDIO approach.

This approach defines the 'what' through its syllabus and the 'how' through the 12 interrelated standards shown here. These standards are interrelated and delivered to teaching staff through standards 8 and 10 in a learning community model.

Figure 1b. Connecting the dots… Understanding Our Approach to Education Initiatives.

It was believed that making sense of various initiatives through the contextualisation of pedagogical efforts was essential to increase faculty awareness and relevance in their teaching practices. Scaffolding pedagogical initiatives' relevance in the context of faculties' own teaching practices potentially helps connect their work to their personal values, goals, and beliefs. The annual event was held on the 5th of March 2024 and was attended by 65 and 36 colleagues from ABE and SMA, respectively. The TLMS from both schools collaborated to identify two pedagogical initiatives (Figure 2) organized as two tracks for the 2024 symposium: Track 1 - Facilitating Teamwork Measurement Conversations and Track 2 - Mechanics of Data-Enabled Flipped Learning (DEFL).

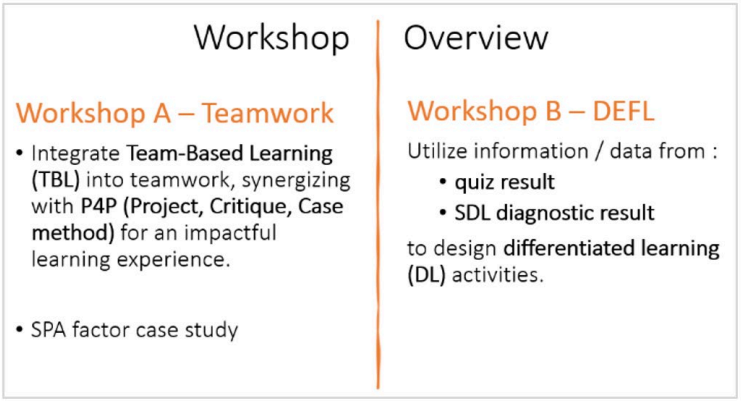


Figure 2. Two Tracks for the Symposium.

In the design of Track 1, TLMS from ABE and SMA collaboratively surfaced 'case studies' from their experiences for the participants to study real-life classroom problems on Teamwork based on different pedagogical scenarios and explore practical solutions through collaborative sharing and learning and thus enhance individual development in Teaching and Learning. This sharing of experiences offers participants a candid view of the Teamwork Measurement Pedagogy. More importantly, co-creating potential solutions in mediating conflict within student groups will be valuable in charting their pedagogical trajectories ahead.

In the design of Track 2, the mechanisms of DEFL were explored as an introductory session and concluded with a collective brainstorming activity. The central sharing investigated various challenges and addressed misconceptions that might have deterred faculty from adopting the DEFL model in their classes. Faculties from multiple programs collectively brainstormed how students' async quizzes can be harvested as data to support SP's DEFL model via an initial scan and analysis to identify current pedagogical/curriculum gaps contextualized in their diplomas.

As the initiatives detailed in both tracks were relatively new and had started to gain traction in both schools, building confidence and competencies were targeted as crucial outcomes for the participants. The two informal breakout sessions were conceived as 'safe' spaces for faculty to mingle informally as participants shared their experiences and challenges with these educational initiatives. The level of cross-pollination between different faculties from different schools will see significant levels of exchange as their experiences and anecdotes were built on foundations of camaraderie.

The critical mechanism and format of the annual ALC symposium support faculty members in implementing successful evaluation processes, congruent with the CDIO Framework's emphasis on outcomes-based education. By sharing assessment best practices and engaging in evaluation approach discussions, academics can ensure that their assessments assess the desired learning objectives and competencies outlined in CDIO standards. These notions explicitly support the operationalization of CDIO Standards 7 (Integrated Learning Experiences) and 8 (Active Learning), emphasising the importance of effective teaching and learning methods in engineering education (Red'ko & Shadrin, 2014; Tyflopoulos et al., 2021). ALCs help continuously improve teaching quality in engineering courses by allowing academics to engage in professional development, share ideas, and implement innovative instructional approaches (Red'ko & Shadrin, 2014). In addition, ALCs strongly support CDIO Standard 10, which emphasises the need to enhance faculty members' teaching practices and professional growth supported by Eib & Miller (2006).

EXPLORATION FRAMEWORK & RESULT

Feedback from the 2023 symposium revealed an overall satisfaction rate of 25% extremely satisfied, 55% very satisfied, and 20% somewhat satisfied. For the 2024 symposium, a qualitative framework was introduced to assess the effectiveness of ALC in fostering pedagogical strategies. Reflections and feedback from participants of the 2024 symposium were collected via a digital portal, highlighting experiences, challenges, and insights on teaching practices and professional growth. Three key themes were identified: Pedagogy and Student Quality, Teaching Practices, and Feasibility, summarized in Table 1, with general sentiments detailed in Table 2.

DISCUSSION & IMPLICATIONS

The ALC Symposium demonstrated the potential of large gatherings to bridge the gap between disparate educational initiatives and foster a cohesive understanding of pedagogical practices.

A key theme in Pedagogy and Student Quality was the faculty's recognition that the pedagogical strategies shared might not align with their signature pedagogy or universally improve student achievement. However, they acknowledged the potential for increased student motivation. This raised questions about how educators define 'academic success'—

whether it is based on academic performance or fostering intrinsic motivation for lifelong learning or other measurements. As Ekşi et al. (2020) noted, motivation is closely linked to lifelong learning, and faculty members' motivation to innovate in their teaching is positively associated with their drive for lifelong learning competence (Youngsun & June, 2019). Engaging in cross-faculty learning communities (LC) can further enhance faculty motivation, helping them experiment with new strategies and learn from colleagues' experiences.

Table 1. Pertinent Thematic Learning Reflections emerged from Thematic Analysis.

Pedagogy and Student Quality	**Teaching Process and Practices**	**Feasibility**
The pedagogies expounded (especially DEFL's Differentiated Learning) may not necessarily improve student quality but can benefit motivated students.	Effective teaching involves identifying, addressing gaps, and validating findings through a structured process.	Pedagogical approaches discussed are practical and can be implemented using various strategies and templates.
Participants' Reflections: *"DEFL may not improve students' quality. In addition, differentiated learning may help those who are motivated to pass a module (course)."*	**Participants' Reflections:** *"Teaching can be made more effective by following a process where discrete steps are taken to identify the gaps, address them and validate your findings."* *"The inclusion of a case study on the effects of the SPA factor (from self and peer assessments) was particularly valuable. It offered practical insights into how such evaluations can enhance team dynamics and individual accountability."*	**Participants' Reflections:** *"DEFL approaches and strategies. Templates to help guide us to design the interventions."*

The theme of Teaching Process and Practices has encouraged faculty to view their pedagogical efforts as structured processes of identifying gaps, addressing them systematically, and validating findings through reflective practice. Traditionally, educators' pedagogical knowledge has been introspective and incremental, often treated as private knowledge. Large-scale ALC provides a platform for sharing and articulating these experiences, practices, and new insights, promoting a deeper understanding of teaching methods (Mohamed et al., 2022). As faculties are constantly faced with the challenge of time, many may find that the discursive approach to reflection practices may be more feasible. The faculty may also take this opportunity to reflect on their pedagogical approaches and experiences.

Feasibility highlighted the positive reception towards implementing pedagogical approaches shared at the annual ALC Symposium. Time-constrained faculty appreciate the availability of tangible tools and templates to support new teaching methods. As Mezirow et al. (2014) noted, templates can be adapted for higher education, aligned with the course's pedagogical goals. Burgess et al. (2008) similarly recommended templates, noting that they help alleviate the stress of translating subject content into actionable strategies for active engagement. These

tools reduce workload and stress by providing a structured format for streamlining curriculum content, enabling faculty to identify areas for improvement and enhance student learning outcomes. Using templates was also explored by Leong (2021) of which the 'Evidence-based Reflective Practice' templates was administered to at-risk students. The structured templates predicted learning effectiveness before lessons and function as an interventive tool and data collection instrument.

Table 2. Participants' Sentiments

Cautious Optimism	**Appreciation and Gratitude**	**Commitment to Development, Mediating Disagreements and Conflicts in Teamwork Situations**	**Encouragement for Data-Driven Approaches**
There is a sense that while **DEFL** may not improve student quality universally, it is seen as a practical and doable approach with the right strategies and motivation.	Participants appreciated the opportunity to see how team-based learning strategies can be seamlessly integrated into teamwork development. Positive sentiments are expressed towards contributors and educators who shared their insights and experiences, indicating a supportive and collaborative community.	Despite cultural challenges, educators are committed to integrating **Teamwork** strategies and **DEFL** into their courses, showing dedication to improving teaching methods. Through the teamwork workshop, educators now see how self and peer assessment aids.	Positive views on using quizzes and data collection to inform teaching practices highlight a proactive approach to improving education.

Participants expressed cautious optimism, appreciation, gratitude, commitment to development, and support for data-driven initiatives, while also addressing teamwork conflicts. These sentiments highlight the value of a large-scale learning community that fosters cross-disciplinary idea sharing guided by the CDIO Standards. The ALC has provided academics with opportunities to strengthen and apply new knowledge to their teaching practices.

The findings indicate that while challenges persist, there is a solid foundation for continued growth in teaching practices through large-scale learning communities. The importance of contextualizing pedagogical initiatives to align with faculty values and beliefs is crucial. Institutions should prioritize creating learning communities that help faculty connect new teaching approaches with their personal goals. The general sentiment is that the CDIO approach may need to be more relevant to specific courses. To increase its adoption, future symposiums should focus on helping faculty contextualize CDIO in their pedagogy, enhance motivation to experiment with new ideas using templates, and encourage sharing both successes and challenges to demonstrate that failures lead to future success.

Limitations

This study has several limitations that affect the reliability and validity of the findings. The small sample size may limit the diversity of perspectives on the impact of ALCs on faculty. While the

varied roles and experiences of participants added richness, the results may need to be more generalized to other educational contexts due to factors like organizational culture and departmental priorities. The exclusive use of qualitative analysis may have restricted the breadth of data, with some participants deterred from fully reflecting. Future symposiums should encourage more detailed responses, and future research should include both qualitative and quantitative methods to provide a more comprehensive understanding of the impact. Promoting a culture of collegiality and shared learning among faculty is essential for improving teaching quality and professional growth.

CONCLUSION

This study explores the potential of a large-scale faculty LC symposium between two schools with different disciplines and pedagogies, viewing their diversity as an opportunity for cross-pollination. It aligns with CDIO standards 8 and 10, particularly in enhancing teaching competence. The positive faculty responses suggest a path for future joint CDIO-focused events. Key findings from participant reflections highlight themes such as Pedagogy and Student Quality, Teaching Process and Practices, and Feasibility. The faculty expressed cautious optimism, commitment to improvement, and support for data-driven approaches, underscoring the importance of CDIO-driven symposiums for fostering faculty development and pedagogical innovation.

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BIOGRAPHICAL INFORMATION

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ENHANCING TECHNICIANS' KNOWLEDGE OF CDIO THROUGH GENERATIVE AI

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ABSTRACT

In the CDIO ecosystem at Singapore Polytechnic, technicians serve as a critical bridge between academic instruction and hands-on student learning, embodying an essential but often under-recognized role in education. While technicians play a pivotal role in delivering and supporting learning, many view themselves as lacking expertise in teaching and learning compared to lecturers, resulting in a diminished sense of professional identity. To address this gap, we propose a novel approach to professional development tailored for technicians: a personalized, on-demand chatbot that supports continuous, situated learning aligned with their daily responsibilities. The chatbot was developed based on the "5 Moments of Need" theoretical framework, a model that posits five essential moments when learning is most impactful. This framework allows the chatbot to serve as a just-in-time learning resource that technicians can access anywhere and anytime. By leveraging this model, the chatbot is designed to deliver targeted content, formative assessments, and personalized feedback. To test the effectiveness of this approach, a prototype chatbot was introduced to a select group of technicians, providing them with on-demand, personalized learning experiences tailored to their specific needs within the CDIO framework. Initial feedback and usage data indicate that this chatbot has the potential to significantly increase engagement, bolster technicians' confidence in their instructional roles, and accelerate the acquisition of relevant skills. This paper will discuss the potential improvements for enhancing the chatbot's capabilities. The broader implications of this personalized learning tool for the global CDIO community are substantial, offering a scalable, sustainable, and flexible solution that allows technicians to upskill efficiently within their professional environment.

KEYWORDS

Artificial Intelligence, Professional Development, Chatbot, Standards 9, 10

INTRODUCTION & BACKGROUND

Technicians play an increasingly vital role in the CDIO (Conceive-Design-Implement-Operate) ecosystem of engineering education, particularly in institutions like Singapore Polytechnic. Traditionally regarded as support staff, technicians have seen their responsibilities expand to include aspects of teaching and learning, such as mentoring students in CDIO projects, creating asynchronous instructional content, and assisting in lab-based learning. Despite their growing involvement in instructional practices, many technicians express a lack of confidence in their teaching competence and pedagogical knowledge. This is compounded by their perception of being less qualified than academic staff, which may reduce their willingness to engage in formal professional development focused on education.

Existing professional development (PD) programmes often fall short of meeting technicians' needs. These programmes tend to follow a "just-in-case" model, delivering broad content that is not always directly relevant or immediately applicable to technicians' daily tasks. Furthermore, traditional PD formats like workshops and seminars may not fit well into technicians' work routines, contributing to low engagement and uptake. Literature also suggests that non-academic staff often feel disconnected from pedagogical training designed primarily for academic professionals, further diminishing their motivation to participate.

To address these challenges, this study explores the use of a personalised AI-powered chatbot as an alternative approach to professional development for technicians. Built upon the "5 Moments of Need" framework (Mosher & Gottfredson, 2011), the chatbot offers just-in-time, contextualised learning that technicians can access at their convenience. It provides personalised feedback, formative assessments, and guidance based on a defined body of knowledge aligned with CDIO principles.

By leveraging generative AI, the chatbot facilitates micro-learning and enables technicians to self-direct their learning at a pace and depth suited to their needs. As such, the chatbot not only improves access to professional development but also aligns with the evolving role of technicians in modern engineering education.

This study is guided by the following research questions:

1. How do technicians perceive the chatbot in supporting their professional development needs related to CDIO (Perceived Usefulness)?
2. How easy is the chatbot to use for learning CDIO concepts (Perceived Ease of Use)?
3. What is the level of intention among technicians to continue using the chatbot (Intention to Use)?

LITERATURE REVIEW

Technicians play an essential role in educational settings, bridging the gap between theoretical knowledge and practical application. However, traditional professional development (PD) programs often fail to meet their unique needs. One major limitation lies in the "just-in-case" approach commonly found in PD, where training is delivered as generalized content rather than tailored to the specific, immediate needs of technicians. This approach can lead to disengagement, as technicians often perceive the training content as irrelevant to their practical roles, which require context-specific learning that supports daily tasks (Mosher & Gottfredson, 2011).

Research highlights additional issues, such as a lack of flexible scheduling in traditional PD, which often relies on scheduled workshops and seminars that may not align with technicians' work responsibilities. Inflexible delivery methods hinder participation and limit the immediate applicability of learned skills (ASAECenter.org, 2017). With rapid technological advancements impacting various fields, technicians frequently require timely training updates that traditional PD formats cannot provide quickly enough (Techademy, 2023). Additionally, technicians, who do not view themselves as equals to academic staff, may hesitate to engage fully in PD activities focused on pedagogy, resulting in limited skill development and low confidence in instructional tasks (Graham & Regan, 2016). This reluctance underscores the need for a new PD approach that fosters engagement and supports the evolving instructional roles of technicians.

An emerging body of literature suggests that technology-enabled solutions could address these limitations, with many experts advocating for “just-in-time” PD as a more effective alternative to the traditional “just-in-case” approach. Just-in-time learning aligns closely with the immediate, context-driven needs of technicians by providing tailored, accessible content that can be applied directly to tasks at hand (Gottfredson & Mosher, 2011). Additionally, technology-based PD tools, particularly personalized chatbots, have shown promise in creating adaptive learning experiences that address individual user needs and knowledge gaps in real time (Khan et al., 2019). These chatbots provide an innovative way to support technicians through interactive, flexible PD that eliminates the time and location constraints of traditional training.

Chatbots can serve as valuable tools for delivering personalized learning aligned with the “5 Moments of Need” framework, which identifies five critical instances when learning support is most beneficial: learning something new, expanding upon existing knowledge, applying or remembering information, solving problems, and adapting to changes (Mosher & Gottfredson, 2011). By offering two-way interactions that adapt to users’ learning progress, chatbots facilitate just-in-time learning that supports technicians precisely when they need it. Chatbots can also provide immediate feedback, answer queries, and guide users through customized learning pathways, allowing them to learn at their own pace and according to their specific needs. This capability is particularly relevant to technicians, whose PD needs vary widely based on their roles and responsibilities.

Moreover, chatbots can create a supportive, non-judgmental learning environment that encourages technicians to explore instructional concepts without fear of being compared to academic staff. Research shows that personalized chatbots help reduce anxiety around learning by tailoring content to users' existing knowledge and presenting it in an approachable way (Fryer & Bovee, 2016). This personalized feedback mechanism allows chatbots to monitor learning progress, offer targeted exercises, and suggest relevant resources that align with each user’s learning journey (Lemoine & Richardson, 2019). The combination of on-demand, personalized learning and just-in-time accessibility positions chatbots as an effective tool for delivering PD that meets technicians' unique needs.

In summary, the integration of the “5 Moments of Need” framework with personalized chatbot technology offers a transformative solution to the limitations of traditional PD for technicians. By delivering context-specific, adaptive learning experiences, chatbots address technicians' immediate needs while supporting their continuous development in both technical and instructional competencies. This innovative approach aligns with current educational trends emphasizing flexibility, accessibility, and learner-centered PD, marking a significant shift toward more effective professional growth for technicians.

Using Chatbots to Meet the Unique Needs of Technicians

In response to the professional development needs of technicians within the CDIO framework, this paper presents a personalized chatbot solution designed to deliver on-demand, context-specific learning aligned with the "5 Moments of Need" model. Built on OpenAI's GPT-4 language model. This model was chosen for its advanced natural language processing capabilities and ability to generate contextually appropriate responses from acurated database of CDIO-aligned resources. The following sections outline the key functionalities of this chatbot, its alignment with the 5 Moments of Need, and how it directly supports technicians' unique requirements for professional growth. Please refer to Figure 2 below for the interface.

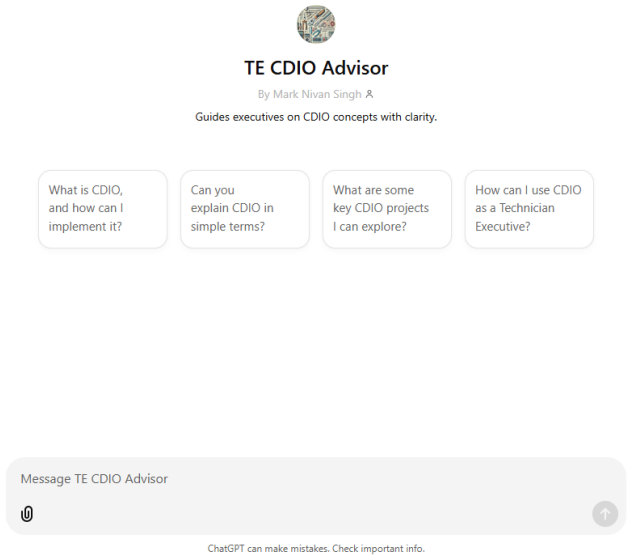


Figure 1. Chatbot Interface

CHATBOT DESIGN & KEY FUNCTIONALITIES

Flexible Access to Learning Resources

The chatbot is available at any time through a simple link, enabling technicians to access learning support without waiting for formalized professional development sessions. This feature promotes continuous, self-directed learning, which is particularly advantageous for technicians with varied schedules and immediate learning needs (Kumar, S., & Shah, A., 2021).

Prompt-Driven Interactivity

The chatbot is highly responsive to technician prompts, adapting its responses based on the specific learning intentions expressed by the user. For instance, technicians may choose to test their knowledge by prompting the chatbot to create multiple-choice questions (MCQs). Upon completing the questions, technicians receive personalized feedback based on their answers. If needed, the chatbot will offer additional formative assessments or learning resources until the technician decides to conclude the session. Research shows that micro-

learning strategies, like these brief and targeted assessments, can significantly improve retention and reinforce learning by promoting frequent engagement with new concepts (Li, M., & Tsai, P., 2020).

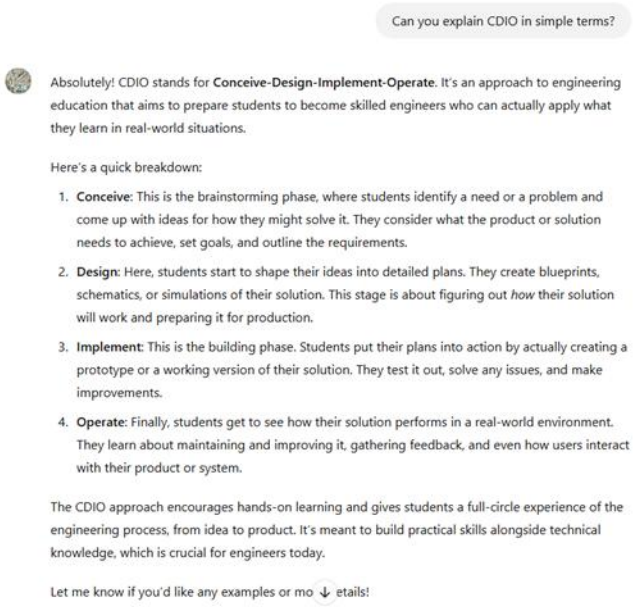


Figure 2. Prompt-Driven Interactivity

Content Integrity and Approved Knowledge

The chatbot's responses are drawn exclusively from an established body of knowledge, ensuring that technicians receive only vetted and relevant content. This design limits the risk of misinformation and aligns with institutional knowledge standards, allowing technicians to build confidence in the accuracy of the information they receive (Smith, J., 2018).

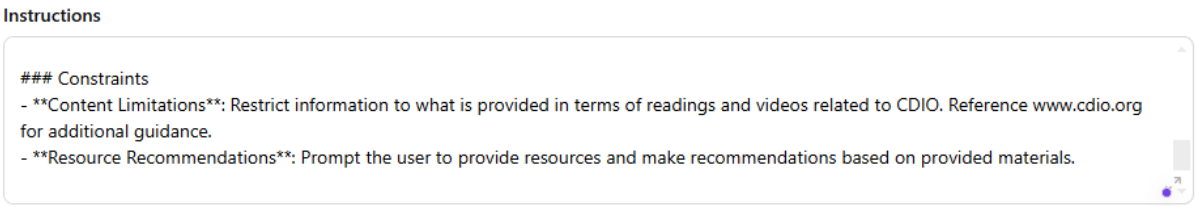


Figure 3. Boundaries provided to the Chatbot to maintain content integrity

Meeting Technicians' Specific Needs

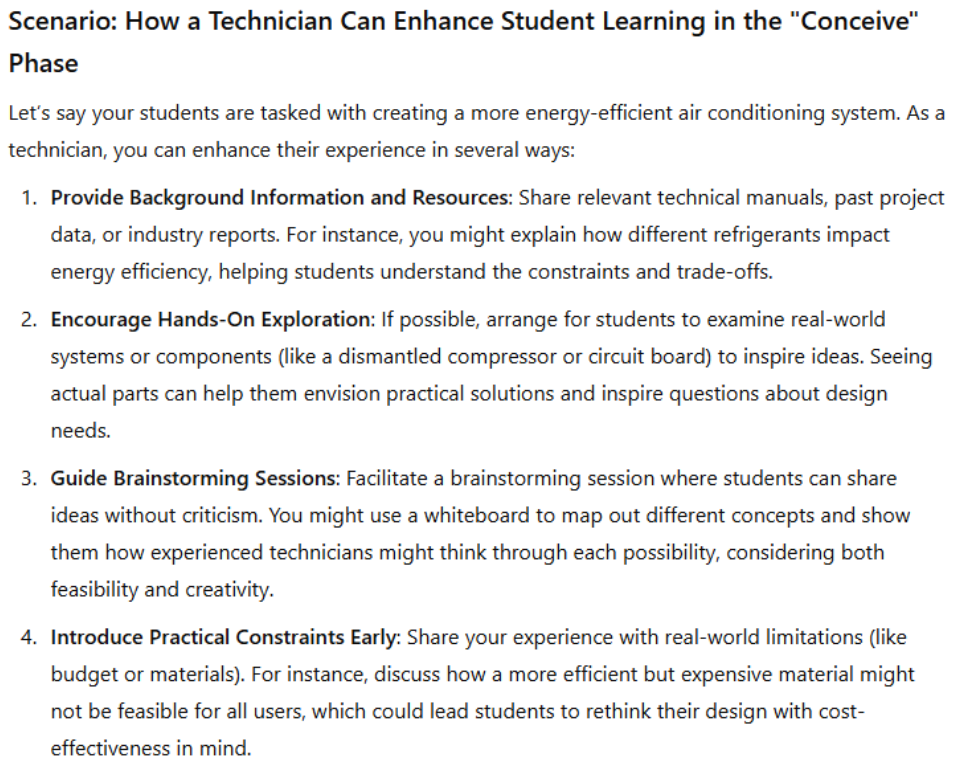
The chatbot's design and functionality are well-suited to meet the specific professional development needs of technicians, as detailed below:

Flexible and Accessible Learning

The chatbot's anytime-access nature ensures that technicians can learn at their convenience, supporting ongoing development without disrupting their core responsibilities (Brown, 2019).

Personalized Feedback and Adaptive Learning Pathways

Through personalized responses and tailored assessments, the chatbot adapts to each technician's knowledge level, providing customized feedback and suggesting additional resources as needed. This individualized support can help technicians feel more confident and engaged with the learning material (Fryer, L., & Bovee, H., 2016). Figure 5 below shows the ability of the chatbot to provide short formative assessments to test the learning of technicians to ensure that they are learning effectively as well as provide use cases to reinforce learning



Scenario: How a Technician Can Enhance Student Learning in the "Conceive" Phase

Let's say your students are tasked with creating a more energy-efficient air conditioning system. As a technician, you can enhance their experience in several ways:

1. **Provide Background Information and Resources**: Share relevant technical manuals, past project data, or industry reports. For instance, you might explain how different refrigerants impact energy efficiency, helping students understand the constraints and trade-offs.
2. **Encourage Hands-On Exploration**: If possible, arrange for students to examine real-world systems or components (like a dismantled compressor or circuit board) to inspire ideas. Seeing actual parts can help them envision practical solutions and inspire questions about design needs.
3. **Guide Brainstorming Sessions**: Facilitate a brainstorming session where students can share ideas without criticism. You might use a whiteboard to map out different concepts and show them how experienced technicians might think through each possibility, considering both feasibility and creativity.
4. **Introduce Practical Constraints Early**: Share your experience with real-world limitations (like budget or materials). For instance, discuss how a more efficient but expensive material might not be feasible for all users, which could lead students to rethink their design with cost-effectiveness in mind.

Figure 4. Formative Assessment to Check for Learning

In summary, the chatbot's functionalities address the immediate, context-specific learning needs of technicians by aligning with the "5 Moments of Need" framework. By enabling real-time, interactive, and accurate learning experiences, the chatbot represents a significant advancement in professional development approaches for technicians, making PD both accessible and relevant to their evolving roles.

TESTING APPROACH & STATISTICAL ANALYSIS

This study adopted a quantitative approach to evaluate the chatbot's effectiveness based on the Technology Acceptance Model (TAM) constructs: Perceived Usefulness (PU), Perceived Ease of Use (PEOU), and Intention to Use (ITU). A validated TAM-based questionnaire (Davis, 1989; Venkatesh & Davis, 2000) was administered to 35 technicians following their interaction with the chatbot.

Given the exploratory nature of this study and the relatively small sample size, the analysis employed descriptive statistics rather than inferential testing. The rationale for using descriptive statistics is to provide an initial overview of participants' experiences and perceptions. This approach is common in early-phase educational technology evaluations where the aim is to understand user reception before scaling up to broader implementations (Nouri, 2018).

A total of 35 technicians from the School of Electrical and Electronic Engineering and the School of Mechanical and Aeronautical Engineering took part in the questionnaire. Please refer to Annex A for the questionnaire.

Key statistical measures reported include mean, median, and standard deviation for each TAM construct. The analysis focused on highlighting general trends in user responses, which inform future iterations of the chatbot and potential avenues for expanded research.

It is also worth considering that one factor contributing to the variance in user responses—particularly in Perceived Ease of Use—may be differences in English language proficiency among technicians. As the chatbot currently operates exclusively in English, technicians with lower fluency might face challenges in interpreting or constructing effective prompts. This aligns with findings from Lin and Warschauer (2015), who observed that language proficiency significantly impacts learners' interactions with digital tools in educational contexts.

To support ongoing refinement, technicians provided feedback on areas where the chatbot experience could be improved. Suggestions included the provision of sample prompts to help users get started, expansion of the knowledge base to minimise incomplete responses, and inclusion of a simple dashboard to track learning progress. There were also calls to address institutional ethical compliance and to enhance the chatbot's tone to simulate more human-like interaction. While these suggestions were touched upon in earlier sections, their consolidation here serves to highlight key priorities for future development.

Beyond improvements to the chatbot itself, it is also important to consider the broader educational impact of this intervention. As technicians become more confident and competent in applying CDIO principles, the quality of student learning experiences can improve. For example, better-prepared technicians may facilitate more effective lab demonstrations, provide more insightful mentorship during project-based learning, and offer timely, accurate feedback aligned with CDIO goals. This strengthens the link between theory and practice, ultimately enhancing the outcomes of engineering education for students.

One specific limitation raised by participants relates to the perceived tone of the chatbot. While functionally accurate, the chatbot responses were occasionally viewed as too formal or impersonal, lacking the warmth of human interaction. This is a known limitation of current AI-driven dialogue systems, which, despite natural language capabilities, often struggle to convey empathy or adapt tone effectively to diverse user expectations (Følstad & Brandtzæg, 2017). Future iterations could explore integrating sentiment-aware language models or hybrid AI-human support systems to mitigate this.

RESULTS & DISCUSSION

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Limitations of the Technology Acceptance Model

Although the TAM has been validated in many studies, the actual usage of the technology, as opposed to the behavioural intention to use, is rarely monitored. Furthermore, this may lead to a mistaken belief in the acceptability of a technology. For example, a study conducted by Keung et al. found that the TAM predicted that a particular technology was likely to be adopted within the company in question. However, a year later the authors found that the technology was not being used. The TAM was re-applied at the later time and the results from this study were different from the initial TAM assessment. Therefore, there is a question as to whether the TAM can act as an accurate predictor of actual usage rather than behavioural intention to use. The suggestion here then, would be to re-administer the TAM again after a year of implementation.

CONCLUSION

The personalised chatbot developed for this study demonstrates promise as an innovative and accessible form of professional development for technicians operating within CDIO environments. By offering on-demand learning grounded in the 5 Moments of Need framework, the chatbot addresses many limitations of traditional PD formats while encouraging technician-led, micro-learning experiences. User feedback indicates high levels of perceived usefulness, ease of use, and intention to continue using the chatbot in daily work.

Notably, this study also highlights areas for improvement, such as enhancing tone, expanding the knowledge base, and ensuring inclusivity for varying levels of English proficiency. The findings point to a broader impact: as technicians gain confidence in their CDIO understanding, students benefit from more effective lab supervision, timely mentorship, and stronger integration of theory with practice.

Future work will involve refining the chatbot based on technician input, exploring integration with institutional systems, and extending its application to other professional development domains.

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BIOGRAPHICAL INFORMATION

Mark Nivan Singh is Deputy Director of Educational Development at Singapore Polytechnic. Mark leads in the implementation of education initiatives like CDIO, Data-Enabled Flipped Learning, Self-Directed Learning and Pedagogy for the Professions. Part of his work involves working closely with faculty to re-design their curriculum, innovate their teaching and learning approaches and conducting relevant workshops and other professional development activities to enhance the capability of SP's faculty in teaching and learning.

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OPERATIONALIZING CDIO ENGINEERING LEARNING WORKSPACES IN EAST KAZAKHSTAN TECHNICAL UNIVERSITY

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ABSTRACT

This paper discusses the effort by East Kazakhstan Technical University (EKTU) in collaboration with Singapore Polytechnic (SP), in using the CDIO Standard 6 Engineering Learning Workspaces to align EKTU's Luban Workshop (EKTU and China's Tianjin Vocational Institute collaborative project). EKTU had earlier adopted the Chinese teaching model Engineering Practice Innovation Project (EPIP) for its Luban Workshop. The paper shares a brief literature review on CDIO workspaces, SP experience in CDIO Standard 6 implementation, combined use of the CDIO and EPIP in engineering education. This paper concludes with ideas for moving, including the design thinking integration and students survey learning experience.

KEYWORDS

Learning workspace, Luban Workshop, CDIO Standard 6.

INTRODUCTION AND SCOPE OF THIS PAPER

East Kazakhstan Technical University (EKTU) joined the CDIO initiative in 2023. Currently the institution is the only university implementing the concept of engineering education based on international standards and the CDIO initiative in Central Asia and Kazakhstan. This is in line with the university's effort towards reinventing its approach to conducting engineering education based on practice-oriented models of engineers' preparation aligned to international standards. This started in 2023, under a scientific project funded and guided by the Ministry of Education and Science of Kazakhstan, East Kazakhstan Technical University developed the National Model of Engineering Education for Kazakhstan practices. The Worldwide CDIO initiative and Chinese teaching model Engineering Practice Innovation Project (EPIP) were chosen as the foundation of the Kazakhstan model. The main elements of EPIP comprise 4 elements which are "Engineering", "Practice", "Innovation", and "Project". "Engineering" of EPIP means real life-oriented, industrialized, realistic, socialized projects. "Practice" reflects simultaneous study of theory and practice. "Innovation" means trying new things, using new concepts, development of original solutions. "Project" of EPIP characterizes development of cognitive competence, independent thinking, logical reasoning, expression ability, information processing, word application, ability of cooperation, self-control, team-working, innovative thinking via project-based learning (Lyu, 2022). As a result of this project, East Kazakhstan Technical University aims to share own experience of implementing these standards with all technical universities in Kazakhstan by 2025.

One of the key focus areas is to align the various engineering learning workspaces within the East Kazakhstan Technical University campus in Oskemen. A notable feature of the workspaces in this university is a recently introduced Luban Workshop, set up with the assistance from the Tianjin Vocational Institute from China (Lyu, 2022). The workshop, opened in December 2023, is named after Luban, who was a Chinese architect or master carpenter, structural engineer, and inventor, during the Zhou Dynasty; and revered as the Chinese Deity (Patron) of builders and contractors. Using the teaching model of EPIP, students in the Luban Workshop will be trained in transportation equipment and technology, with four practical training areas: fuel vehicle maintenance, fuel vehicle systems, new energy vehicles and intelligent connected vehicles.

Being a new member of CDIO, East Kazakhstan Technical University actively engaged in learning about best practices from other CDIO collaborators. One area is to harmonize the teaching and learning approaches in their engineering programs with their engineering learning workspaces, especially with a view to supporting the EPIP. To this end, selected university faculty embarked on a learning journey to Singapore Polytechnic in March 12-15, 2024; with the aims of learning about using CDIO for curricular continual improvement and accreditation; with special focus on how workspaces are used in the School of Mechanical & Aeronautical Engineering, to support student projects and collaboration with industry partners.

This paper shares the outcomes of the initial working partnership between East Kazakhstan Technical University and Singapore Polytechnic. It first presented relevant information of learning workspaces framed within the CDIO perspectives. It then provides a use case of how Singapore Polytechnic enhanced its CDIO adoption with design thinking framework to drive innovation from student projects and share the example of the Singapore Polytechnic Aero Hub as a specific example of how learning workspaces is used to engage students in learning. The paper then moves on to explain work done in East Kazakhstan Technical University with respective to the development of the Luban Workshop.

LITERATURE REVIEW

The "learning by doing" approach has been widely recognized as an effective method in engineering education due to its active learning principles. This method emphasizes hands-on experiences, problem-solving, and real-life simulations, which are crucial for developing both technical and soft skills among engineering students. This hands-on approach helps improve retention and mastery of subjects, making students more confident in applying what they have learned to real-world problems (Bot et al., 2005). An industry-based learning space affords authentic learning for a particular industry sector. Gibson et al (2009) highlighted that a “work-based learning gives students the opportunity to develop both general and field-specific skills, such as personal, communication, teamwork and research skills, experience in project design and management, professional work experience and the opportunity to secure on going employment”.

CDIO Standard 6 Engineering Learning Workspaces

Core Standard 6 of CDIO explains engineering learning workspaces as “*A physical learning environment that includes engineering workspaces and laboratories that support and encourage hands-on learning of product, process, system, and service building, disciplinary knowledge, and social learning, combined with a digital learning environment that includes on-line tools and spaces that support and enhance the quality of teaching and student learning*”.

Crawley et al (2007, pp.119) provide the essential and desirable attributes of CDIO workspaces as shown in Table 1 and various utilization modes as shown in Figure 1.

Table 1. Essential and Desirable Attributes of CDIO Workspaces

Essential Attributes	• Encourage hands-on learning of product, process, and system design and implementation, while at the same time supporting disciplinary and interdisciplinary knowledge
	• Facilitate student learning of personal and interpersonal skills
	• Facilitate group activities, social interaction, and communication leading to social learning
	• Comply with local health and safety regulations
	• Provide sustainable resources
Desirable Attributes	• Be organized and managed by students
	• Provide flexible equipment, furniture and facilities
	• Facilitate access by students beyond normal class hours
	• Provide access to modern tools, equipment and software

Within the CDIO literature, Cunningham et al (2009) discussed the use of requirement specifications for renovation of existing workspaces or building new workspaces by mapping different types of workspaces (studio room, laboratory, workshop, etc) to the various learning modes of Figure 1. Various institutions had adapted the standard for their own educational needs (e.g. González et al, 2013; Petrova et al 2021). Innovative use had also been reported, for example Clausen & Binder (2017) shared an interesting approach on using the standard for mining engineering. The study concludes that students’ learning success is related to the integration of authentic and innovative learning spaces. Gerlein et al (2018) described how community building among students is achieved by making the Electronics Lab from Pontificia Universidad Javeriana available 24/7. Sluijs et al (2019) described the setting up of a living lab for co-creation at the Hague University of Applied Sciences, that is accessible for all faculties and research programs.

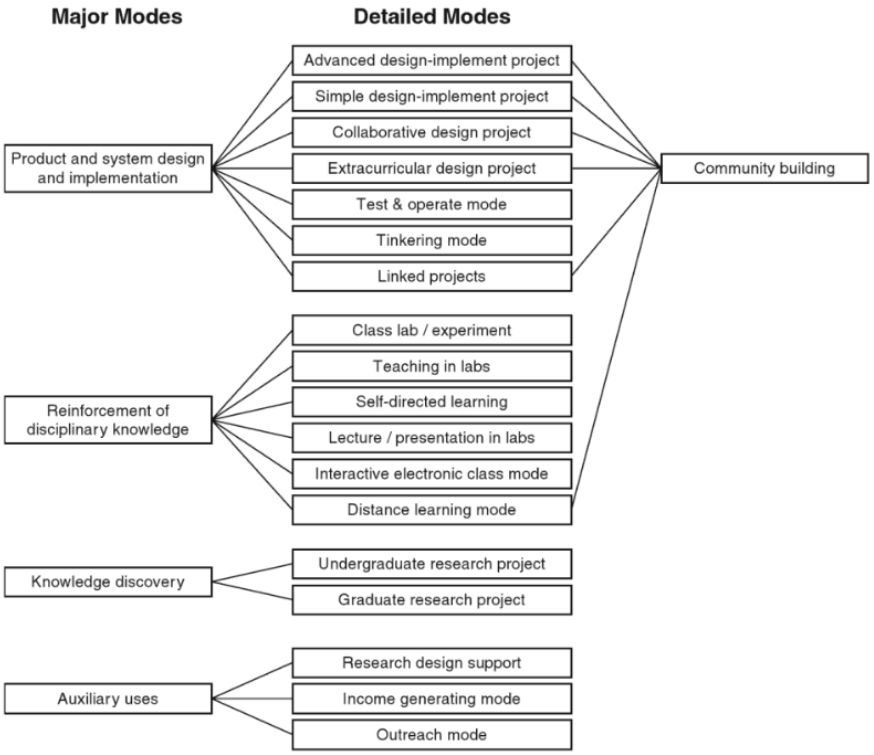


Figure 1. Teaching and Learning Modes in CDIO Workspaces

Key Takeaways from Learning Journey to Singapore Polytechnic

Use of engineering learning workspaces in Singapore Polytechnic is largely organized along this line: Each school retained the laboratories and workshops that supported learning along disciplinary lines, whereby one can easily infer from a facility's name the type of activities contained therein, e.g. Mechanics Lab, Analytical Chemistry Lab, etc. These facilities are dominantly used to instill foundational skills and attitudes (e.g. teamwork and collaboration, communication, critical and creative thinking) within the disciplinary context. There are also specialized labs supporting project works where students worked on their capstone projects, i.e. CDIO design-implement experiences; some of which are in collaboration with industry partners. The project labs supported key project management competencies as shown in Table 2 below.

Table 2. Competencies to be developed from CDIO Design-Implement Experiences

Conceive	Design	Implement	Operate
Define Issues, Analyze Problems	Project Management (Planning, Scheduling, Monitoring, Budgeting etc.)		
Empathy: Identify Needs, Target User	Propose (simulate) Possible Solutions	Build Prototype	Operate Prototype, Prepare Deployment
Background Research	Identify Constraints (incl. Assumptions)	Test, Troubleshoot, Verify	Collect Data, Analysis and Communicate Results
Specify User Requirements and Product Functions	Develop Criteria, Evaluate Alternative Solutions, Select Design, Details and Drafting	Prepare Standard Operating Procedures	Modify or Redesign, Optimise and/or Improve
Prepare Initial Product Concept, Plan	Analyse Impact on Engineering on Society and Environment	Prepare Maintenance Procedure	Consider Disposal Options

To better support the conceiving capacity of its students, Singapore Polytechnic also introduced design thinking into all its curriculum, i.e. it is made mandatory for all students. The Design Thinking Framework when used in conjunction with CDIO, is shown in Figure 2. The detailed information has been presented in Chong et al (2011), Soh (2011), Ng & Cheah (2012).

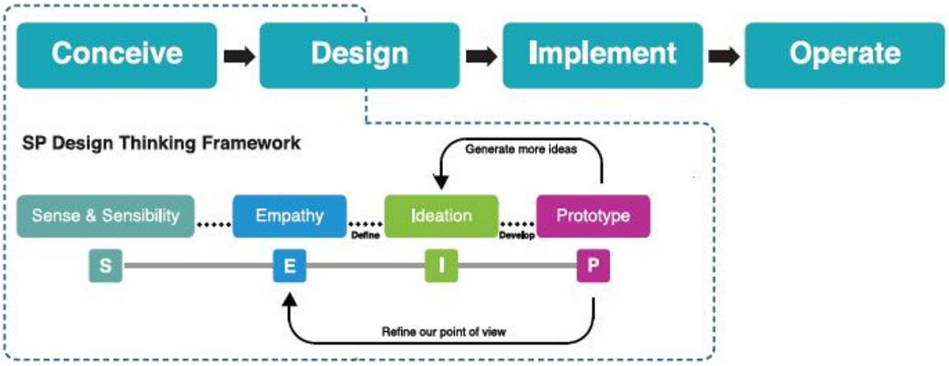


Figure 2. SP Approach to Integrated Design Thinking into CDIO Framework

Of interest for this paper, is the Aero Hub from School of Mechanical & Aeronautical Engineering. The Aero Hub is a four-storey building that provides training facilities to students from the Aeronautical Engineering and Aerospace Electronics programs with authentic training environment. It houses a hangar with several live-size aircrafts and a helicopter, laboratories and Research & Development center that supports the development of full-motion flight simulators, hybrid rocket propulsion systems and vertical take-off and landing vehicle, and Unmanned Aerial Vehicle. The Aero Hub satisfies much of the requirements of CDIO workspaces of Figure 1, namely product and system design and implementation (e.g. design-implement projects), reinforcement of disciplinary knowledge (e.g. class or laboratory experiment), knowledge discovery (e.g. applied research projects, innovative student capstone projects) and auxiliary uses (e.g. outreach and income generating). A full summary of Aero Hub facilitating various courses and their coverage of CDIO syllabus is shown in Appendix 1.

The integration of design thinking into the CDIO Framework and the example of the Aero Hub serve as a good example for East Kazakhstan Technical University to integrate its Luban Workshop into its engineering program which is made up the rest of the discussion for this paper.

EAST KAZAKHSTAN TECHNICAL UNIVERSITY'S ADOPTION OF CDIO TO-DATE

Adoption of CDIO initiative in East Kazakhstan Technical University is conducted by the following educational directions which are mechanical engineering, automotive engineering, energy, construction, water engineering, mining, etc. Workplaces for the implementation of project-based learning process are presented by 12 Competence Centers, 53 training laboratories, 2 workshops equipped by essential training equipment. Among the existing types of workspaces, the most interesting one is Luban Workshop oriented to the preparation of engineers in the field of automotive engineering.

Based on CDIO Standards, a practice-oriented model of engineering education (Figure 3) has been developed which comprises 5 consecutive educational levels. These are: "PU" (pre-university), "c-d" (basic engineering competence), "C-D" (Conceive-Design), "I-O" (Implement-Operate), and "PE" (Postgraduate Education).

"PU" level is pre-university preparation through the work of "engineering classes" in comprehensive schools. Under the pre-university stage the study of advanced physics, mathematics, and IT is conducted using gamification.

“c-d” level is formation of basic engineering qualifications in 1st-2nd year undergraduate students. At this level, students work on a small (simple) project, the purpose of which is to acquire skills in applying the knowledge of natural sciences acquired at school within the framework of the discipline “Introduction to Engineering Education”.

This project is carried out in a special Fab Lab workshop based on the CDIO syllabus and the EPIP model. Fab Lab is a workshop for the creation of creative projects implemented within the framework of the discipline “Introduction to Engineering Education” at the Conceive (C) and Design (D) stages of the World CDIO Initiative. The main objectives are developing basic engineering skills, creating conditions for developing innovative products, a platform for communication between representatives of different Schools and areas of East Kazakhstan Technical University, providing students with access to modern tools and equipment, promoting the development of student startups, and implementing initiatives aimed at solving social problems.

"C-D" level is the formation of deep practical knowledge of the technical foundations of the profession in 3rd-4th year bachelor's students. This level includes the implementation of a more complex project in the specialty based on the professional knowledge acquired at the university. The result of the stage is the definition of the problem and the creation of an engineering model for solving this problem. At the same time, within the framework of this stage, an interdisciplinary approach is possible in accordance with the principle of the EPIP model.

"I-O” level is development of research competencies in 3rd-4th year undergraduate students. At this stage, work is carried out to implement the ideas formed at the previous level. Regarding the educational programs of "Automotive engineering", the implementation of this stage is carried out using the equipment of the Luban Workshop.

“PE” level is training of master's and PhD students on examples of solving production and experimental design problems of specific enterprises and the needs of the regional economy. These are complex interdisciplinary tasks that require the combined efforts of several competence centers, various groups of researchers, which make it possible to implement various technologies which are practical engineering, team educational technologies, project management, start-up, etc.

Aligning the Luban Workshop to CDIO Standard 6

The core of Luban Workshop is the teaching model of EPIP which is the educational strategy directed to the development of practical engineering skills, critical thinking, collaboration, communication, creativity, innovation, cross-disciplinary learning (Getachew, 2023; Ying, 2019). The goal of the Luban Workshop is to create a unique educational and methodological base in Kazakhstan in the field of advanced technologies in road transport. The expected result is a new model of professional and engineering education according to world standards, the translation of advanced technologies, and development of engineering practice taking into account the needs and characteristics of the national economy.

"5 main elements" of the creation of the Luban Workshop:

- Construction of a site with educational demonstration and educational laboratory equipment.
- Educational and methodical equipment and advanced technologies in teaching.
- Directions and specialties for training personnel for local socio-economic development.
- Teacher training with adaptation to local economic and social development.
- Educational resources developed within the framework of cooperation between partner universities and enterprises (Lyu, 2024).

According to EPIP teaching model the desired learning outcomes are the following ones:

- acquiring the real-world engineering experience;
- development of critical thinking and problem solving skills;
- development creativity and innovation;
- development communication and collaboration skills;
- development of skills to use cross-disciplinary approach for problems solving.

The Luban Workshop consists of two sections which are Section of Technologies for Servicing Fuel, Hybrid and Electric Vehicles and Section of SMART-technologies of Vehicles. It should be noticed that all the equipment in Luban Workshop includes innovative Chinese technologies in the field of automotive engineering. The section of technologies for servicing fuel, hybrid and electric vehicles is equipped with contemporary 3 training cars which are Haval H6 (fuel vehicle), BYD (electric vehicle), Haval M6 (hybrid vehicle). In addition, the Section is equipped with modernized training stands for practical study of engine design, engine diagnosis, electrical system, transmission, chassis, battery and electric motor of an electric vehicle, charging station.

The section of SMART-technologies of vehicles includes the sand table for study miniaturized SMART cars, advanced driver assistance systems, and autonomous robotic platform. Using the sand table, students conduct projects related to V2X technologies. Advanced driver assistance systems stand allow realizing the projects connected with providing safety systems while driving a car. Applying the autonomous robotic platform, students implement the project on developing unmanned transport systems.

Aligning the Luban Workshop to CDIO Syllabus

The interesting fact is that Luban Workshop is not only a learning laboratory for students training according to EPIP principles but also a workspace for implementation CDIO standards. Based on CDIO Syllabus 3.0 let us describe the mechanisms for achieving the CDIO learning outcomes using Luban Workshop.

For example, the learning outcomes related to advanced engineering fundamental knowledge, methods and tools according to CDIO Syllabus is achieved by acquiring the skills of work with training equipment on engine assembly and disassembly, engine diagnosing, transmission assembly and disassembly, wheel balancing, tire fitting, lighting system maintenance, battery and traction motor of an electric vehicle maintenance, autonomous system, advanced driver assistance systems by students. The learning outcomes connected with analytical reasoning and problem solving are achieved by solving the problems related to the improvement of parts of fuel, electric and hybrid cars. Experimentation, investigation and knowledge discovery learning results are reached by conducting student research related to, for example, investigation of frost resistance of electric car batteries, parameters of traction battery of electric car, characteristics of engine, etc. System thinking is achieved by taking into account all the factors affecting the effectiveness of electric cars which are ecological problems, energy

efficiency, charging system infrastructure, aerodynamics, etc. Attitudes, thought and learning are achieved by creative and critical thinking used for implementation projects related to maintenance and operation of the automobiles systems. Teamwork and collaboration are reached by organization of the educational process by dividing students into groups. It should be noticed that all the equipment in Luban Workshop is arranged in pairs (Figure 3).

This equipment organization gives the opportunity to realize learning processes based on the development of cooperation, teamwork, and competition. Communications are realized by conducting discussions on the results of projects.

As a result of joint use of CDIO and EPIP, a new format of student engagement is possible for East Kazakhstan Technical University using Luban Workshop. At the point of this writing a course of “Diagnosing of the Automobile Systems” with 15 weeks of contact time can be realized as the competition of 2 student team groups. The teachers create a malfunction in a certain system of the car in advance which leads to its inoperability. The students are offered to tackle this problem. Each project task is the level of the competition and is assessed by scores. The team that completes the task in the least amount of time wins.



Figure 3. Training Equipment Layout in Luban Workshop

Thus, combined use of CDIO principles and Luban Workshop equipment allows us to utilize a new approach for the learning process.

MOVING FORWARD

One area in the CDIO-EPIP Framework that can be enhanced in accordance with Figure 1, is to systematically introduce design thinking into various engineering programs. Referring to the presented teaching and learning modes in CDIO Workspaces (Figure 1), it should be noted that the modes of “Product and system design and implementation” and “Reinforcement of disciplinary knowledge” are covered in Luban Workshop.

For example, under the courses of “Theory of mechanisms, principles of design and machine parts” and “The structure of an electric vehicle and a hybrid vehicle” (Year 2) students realize

projects related to creation of the improved interaction system between automobile elements (Figure 4).

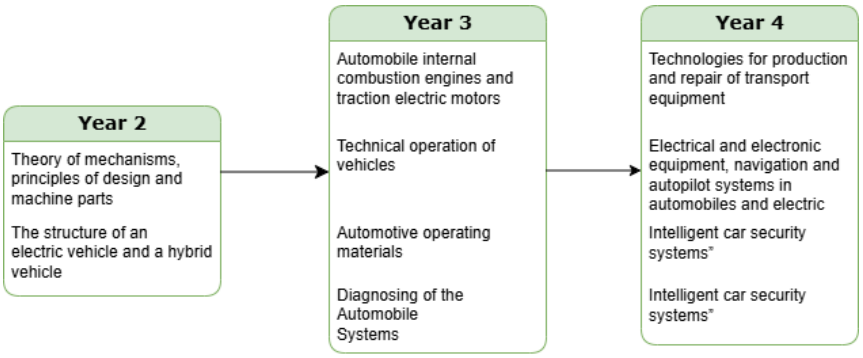


Figure 4. The courses studied in Luban Workshop

To do this, the methods of “Class lab / experiment”, “Teaching in labs”, and “Lecture – presentation in labs” are used. Under the course of “Automobile internal combustion engines and traction electric motors” (Year 3) students implement projects related to the development of the new technical solution on automobile energy source system. Taking the course of “Technical operation of vehicles” (Year 3), students realize the projects connected with new methods of diagnosing of the technical condition of automobiles. Under the course of “Automotive operating materials” (Year 3) students develop projects aimed at improving batteries and charging systems for electric vehicles, creating more energy-efficient batteries, and improving battery life. Based on the modes presented in Figure 3, “Advanced design-implement project” and “Collaborative design project” modes are used for the Year 3 teaching and learning process. Under the course of “Technologies for production and repair of transport equipment” (Year 4) students develop the projects on the creation of the automobile models. Taking the course of “Electrical and electronic equipment, navigation and autopilot systems in automobiles and electric vehicles” (Year 4), students implement the projects related to development of the simple autonomous systems. Under the course of “Intelligent car security systems” (Year 4) students develop projects connected with advanced driver assistance system (ADAS). It should be noticed that in Luban Workshop, the development of students' research competencies is achieved through project-based work using real equipment and technologies in close collaboration with industrial enterprises (Allur, Astana Motors, QazTechna) and interaction with Chinese research centers and universities. This provides opportunities for international knowledge exchange and the publication of research findings in scientific journals. Overall, the LuBan Workshop contributes to the formation of research skills by combining practical training, technological innovation, and international cooperation.

The further intensions are to provide mode of “Knowledge discovery” (conducting of undergraduate and graduate research projects) related to conducting the scientific investigations directed to the improvement of artificial intelligence in the automobiles. To do this, East Kazakhstan Technical University works on the development of the Luban Workshop workspace by building of Section of Smart Driving Technology including the latest technological equipment and electric vehicles implementing “The Internet of Vehicles” SMART-technologies and intelligent driving safety systems, satellite navigation and third-level autopilot. In July 2024, the university teaching staff completed an internship in Tianjin Vocational Institute (China) on the studying contemporary intellectual automobile systems. The undergraduate and graduate research projects will be conducted under new engineering program of “Smart technologies and artificial intelligence in transport engineering”.

CONCLUSIONS

This paper shared how East Kazakhstan Technical University, as a new member of the CDIO community, worked with Singapore Polytechnic, a more-experienced CDIO member, to merge CDIO Framework (notably Standard 6 Engineering Learning Workspaces) into its Luban Workshop which was setup by implementation of CDIO initiative in educational process, coupled with experiences from a learning journey to a more-experienced CDIO member. The Luban Workshop in East Kazakhstan Technical University has been presented, for which the university had merged the CDIO Framework with the EPIP Educational Model. The integration of CDIO and EPIP has led to a transformation of the roles of students and teachers. For students, it impacted them by increasing motivation and engagement, developing professional skills, and fostering innovative thinking. For teachers, it influenced them by changing teaching approaches, enhancing professional competence, and stimulating research activity. Thus, this integration has cultivated a more dynamic, student-centered learning environment where collaboration, creativity, and practical application of knowledge are prioritized.

FINANCIAL SUPPORT ACKNOWLEDGEMENTS

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BIOGRAPHICAL INFORMATION

Zhadyra Konurbayeva is a member of the Board – Vice-Rector for Science and Innovation, PhD in Economic Sciences, East Kazakhstan Technical University. She is the leading CDIO coordinating contact person from East Kazakhstan Technical University. She teaches economic courses related to Sustainable Development Goals. Her scientific interests are connected with development of the Kazakhstani national model of engineering education in the context of Sustainable Development Goals.

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Kim-Fai Soh is a Deputy Director (course management) in the school of Mechanical and Aeronautical Engineering, Singapore Polytechnic. He is leading the school in the implementation of CDIO. He teaches Computer Aided Design, Engineering Design and Renewable Energy. His current pedagogic interests are authentic & experiential Learning with Deep Industrial Participation and Learning with Global Collaboration.

Sin-Moh Cheah is the Centre Director of the SP-CDIO Centre for Innovative Teaching and Learning; under the Department of Educational Development, Singapore Polytechnic. He has more than 17 years of experience implementing CDIO in the Diploma in Chemical Engineering curriculum and had conducted various CDIO workshops for universities in Asia for various disciplinary programs, including non-engineering ones.

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APPENDIX 1. Summary of Zoning of SP Aero Hub for Facilitating Aeronautical Training

Zones	Purpose of training facilities	Domain courses involved	CDIO syllabus covered
Central	• General maintenance of aircraft • Artefacts for case studies * Industry partners: 1. ST Engine-Aero 2. SIAEC 3. SASEL 4. RSAF 5. SUSS	• Aircraft Maintenance Practice/ Gas turbine engine operation/ Aircraft ground handling/ Operational Environmental Training • Computer Aided DesignwithCATIA/ Aircraft structure/ Fundamental of Flight/ AMP • Short courses * *Year 2 & 3*	2.1.1 / 2.2.3/ 2.3.1/2.3.2/ 2.4.1/ 3.2.1/ 3.2.2/4.2.5/ 4.4.1/ 4.5.2/ 4.5.5/ 4.6.1/ 4.6.6/
Ground floor: workshops /Propulsion Test Lab	• Repair aircraft sheet metal &fasteners of aircraft components • Operate and study propulsion systems * Industry partners: 1. ST Engine-Aero 2. ZEN	• AMP • Aircraft powerplant/ Introduction to Space Technology/Final Year Projects * *Year 2 & 3*	2.1.1 / 2.2.3/ 2.3.1/ 2.3.2/ 2.4.1/2.4.4/3.1.2/ 3.2.2/ 3.2.3/ 4.1.1/ 4.2.2/ 4.2.5/ 4.3.1/4.3.2/ 4.3.3/ 4.3.4/ 4.4.1/ 4.4.2/ 4.4.3/4.4.4/4.4.6/ 4.5.2/ 4.5.5/ 4.6.1/4.6.2/4.6.6/
2nd floor Labs	• Aircraft System and Aerodynamics • NDT • Flammability test * Industry partners: 1. JADE	• Aircraft system/ Fundamental of Flight • Short course * *Year 2 & 3*	2.1.1 / 2.2.3/ 3.1.2/ 3.2.2/ 3.2.3/ 4.2.5/ 4.5.5/ 4.6.1/
3rd Floor Labs	• Structural testing lab • Composite repair workshop • VR Learning Space * Industry partners: 1. ACRATS 2. TUM	• Aircraft Structure • Fundamentals of Composite repair • Short course * *Year 2 & 3*	2.1.1/ 2.1.2/ 2.2.3/ 2.2.4/3.2.2/ 3.2.3/ 4.5.2/ 4.5.5/ 4.6.1/ 4.6.5
Simulator Room	• Pilot flight experience * Industrial partners: 1. Primus	• Short course (Private Pilot License Ground Theory (Primus) • Short course (Experiential Pilot Program)	4.5.5/ 4.6.1/ 4.6.2/
Project Centre	• UAV development • General projects	• Final year project • Short course * *Year 2 & 3*	2.1.1/2.1.2/ 2.1.3/ 2.1.4/2.2.2/ 2.2.3/ 2.2.4/ 2.3.1/ 2.3.2/ 2.3.4/ 2.4.1/ 2.4.2/ 2.4.3/ 2.4.4/ 2.4.7/ 3.1.1/ 3.1.2/ 3.1.3/ 3.2.2/3.2.6/ 3.2.7/ 4.1.1/ 4.2.2/ 4.2.5/ 4.3.1/4.3.2/ 4.3.3/ 4.3.4/ 4.4.1/ 4.4.2/ 4.4.3/ 4.4.4/ 4.4.6/ 4.5.2/ 4.5.4/ 4.5.5/ 4.6.1/4.6.2/ 4.6.6/

APPENDIX 2. Summary of Zoning of EKTU Luban Workshop

Zones	Purpose of training facilities	Domain courses involved	CDIO syllabus covered
Section of Technologies for Servicing Fuel, Hybrid and Electric Vehicles	• General maintenance of fuel cars • General maintenance of hybrid and electric cars Industry partners: 1. Astana Motors 2. Allur 3. QazTechna	• Theory of mechanisms, principles of design and machine parts • The structure of an electric vehicle and a hybrid vehicle • Automobile internal combustion engines and traction electric motors • Technical operation of vehicles • Automotive operating materials • Technologies for production and repair of transport equipment	2.1.1 / 2.1.4 / 2.1.5 / 2.2.2 / 2.2.3 / 2.3.1 / 2.4.4 / 2.4.5 / 2.4.6 / 2.4.7 / 3.1.1 / 3.1.3 / 3.2.1 / 3.2.2 / 3.2.6 / 3.3.1 / 4.1.2 / 4.4.1 / 4.5.1
Section of SMART-technologies of Vehicles	• V2X technology training • Training in autonomous vehicle systems Industry partners: 1. Astana Motors 2. Allur 3. QazTechna	• Electrical and electronic equipment, navigation and autopilot systems in automobiles and electric vehicles • Intelligent car security systems	2.1.1 / 2.1.4 / 2.1.5 / 2.2.2 / 2.2.3 / 2.3.1 / 2.4.4 / 2.4.5 / 2.4.6 / 2.4.7 / 3.1.1 / 3.1.2 / 3.1.3 / 3.2.1 / 3.2.2 / 3.2.6 / 3.3.1 / 4.1.2 / 4.4.1 / 4.4.5 / 4.5.1

Annex A

Technology Acceptance Questionnaire

Questions were contextualised to reflect the use of chatbots for professional development.

Perceived Usefulness (PU) of Chatbots for Professional Development

1. Using the chatbot would improve my performance in doing my job	1 – Strongly Disagree 2 – Disagree 3 – Neutral 4 – Agree 5 – Strongly Agree
2. Using the chatbot at work would improve my productivity	1 – Strongly Disagree 2 – Disagree 3 – Neutral 4 – Agree 5 – Strongly Agree
3. Using the chatbot would enhance my effectiveness in my job	1 – Strongly Disagree 2 – Disagree 3 – Neutral 4 – Agree 5 – Strongly Agree
4. I would find the chatbot useful in my job	1 – Strongly Disagree 2 – Disagree 3 – Neutral 4 – Agree 5 – Strongly Agree

Perceived Ease of Use Questions (PEU) of Chatbots for Professional Development

1. Learning to operate the chatbot would be easy for me	1 – Strongly Disagree 2 – Disagree

	3 – Neutral 4 – Agree 5 – Strongly Agree
2. I would find it easy to get the chatbot to what I want it to do	1 – Strongly Disagree 2 – Disagree 3 – Neutral 4 – Agree 5 – Strongly Agree
3. It would be easy for me to become skilful in the use of the chatbot	1 – Strongly Disagree 2 – Disagree 3 – Neutral 4 – Agree 5 – Strongly Agree
4. I would find the technology easy to use	1 – Strongly Disagree 2 – Disagree 3 – Neutral 4 – Agree 5 – Strongly Agree

Behavioural Intention (BI) to use

1. I presently intend to use the chatbot regularly at work	1 – Strongly Disagree 2 – Disagree 3 – Neutral 4 – Agree 5 – Strongly Agree

USING IMMERSIVE VIRTUAL EXPERIMENT TO DEVELOP SAFETY MINDSET AND PROCESS OPERATION SKILLS

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ABSTRACT

The Diploma in Chemical Engineering (DCHE) implemented a suite of skills-based modules in its spiral curriculum to develop in students a safety mindset alongside the technical competencies required by process technicians in chemical processing industries according to the Singapore Skills Framework. Work shared here is from the third skills-based module, *Process Operations Skills 1* (*POS1*) where students will attain process operation skills and safety mindset specifically to prepare process equipment for maintenance. Preparing equipment to render it safe for maintenance requires the application of Workplace Safety and Health (WSH) by identifying hazards and the control measures to take, and applying Safe System of Work (SSoW) framework and Standard Operating Procedure (SOP) based on the process where the equipment is used. In *POS1*, they will extend the WSH knowledge learnt earlier and apply SSoW framework for the first time. Since students were new to mechanical work and have few chances to practice the skills due to limited actual equipment available, DCHE incorporated immersive technology in form of an immersive virtual experiment (IVE) into a learning activity to develop students' competency using control valve isolation as a basis. Thereafter, students had to demonstrate the competency by isolating a pump on an actual test skid. Survey findings showed the IVE was effective as students could better visualise and understand the rationale behind the steps to isolate a control valve. Most felt more prepared to demonstrate knowledge transfer to prepare an equipment for maintenance. Reflections of students' learning experiences using the IVE and subsequent application of learning on the test skid suggested they had acquired skills needed to develop competency in preparing process equipment for maintenance work with a safety mindset. Finally, plans to continue developing safety mindset and technical competences using immersive technology into other skills-based modules are shared.

KEYWORDS

Safety Mindset, Process Operation Skills, Chemical Engineering, Immersive Technology, Standards: 3, 6, 7.

INTRODUCTION

The Diploma in Chemical Engineering (DCHE) at Singapore Polytechnic (SP) trains students to work as process technicians in many industries, including the chemical processing industry. Having a safety mindset is of utmost importance in the chemical processing industry where processes operate at elevated temperatures and pressures using materials that are often hazardous, such as being toxic and flammable. Exercising caution is also needed when carrying out process operating tasks such as starting up a processing plant from ambient condition and preparing equipment for mechanical work due to the hazards present. This paper will focus on the training of students to work as process technicians in the chemical processing industry, specifically to develop the process operation skills alongside a safety mindset needed to perform the task of preparing equipment for maintenance (mechanical work) or after a shutdown.

DEVELOPING SAFETY MINDSET WITH PROCESS OPERATION SKILLS USING CDIO FRAMEWORK

Based on the hierarchy of Info-Communication Technologies (ICT) utilisation suggested by Anderson (2010), this paper adapted the work of Yang & Cheah (2020) to show how safety mindset and process operation skills can be progressively developed with digital technology using the CDIO Framework (Figure 1).

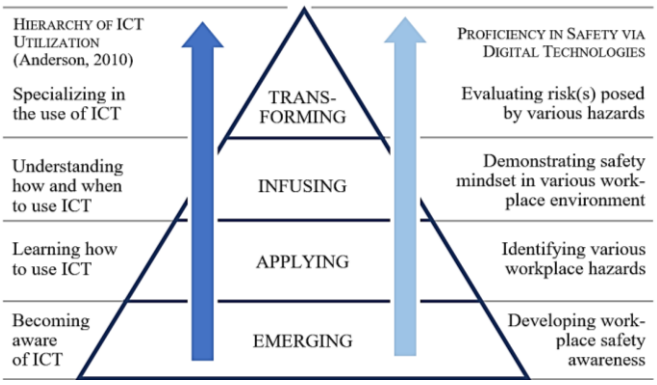


Figure 1. Progressive development of safety mindset using digital technologies

CDIO is an innovative framework for redesigning engineering curriculum that had been used by DCHE since 2007. The CDIO Framework comprises the CDIO Syllabus which guides the writing of learning outcomes and a set of 12 CDIO Core Standards which guides the curriculum redesign process. According to the Job Role Description for Process Technicians referenced from the Singapore Skills Framework (SSF) for the Energy & Chemicals (E&C) Sector (SkillsFuture Singapore, 2017), process technicians perform process operating tasks in the chemical processing industry such as to

- Apply Standard Operating Procedures (SOPs) for process operations
- Perform start-up, monitoring and shutdown of process units and utilities at plant sites
- Prepare process equipment and work areas for mechanical, maintenance and turnaround works
- Support troubleshooting during all modes of operation, including process upset conditions

and require technical competencies such as (1) Standard Operating Procedure (SOP) Development and Implementation, (2) Process Operations Troubleshooting, and (3) Process Equipment Preparation for Mechanical Work at a proficiency level of 2. They will also need to have some of the following technical competencies, such as (4) Workplace Safety and Health Development and Implementation, (5) Workplace Safety and Health Hazard Identification and Risk Control Management, and (6) Safe System of Work (SSoW) Development and Implementation to apply SSoW procedures and comply with Workplace Safety and Health (WSH) systems to perform these tasks safely. Besides these technical competencies, process technicians also require generic competencies such as Teamwork, Communication, and Problem Solving (SkillsFuture Singapore, 2017).

By referencing the above mentioned technical and generic competencies, DCHE used its spiral curriculum, designed using CDIO Standard 3: Integrated Curriculum (Cheah & Yang, 2018) (Figure 2), to develop safety mindset with process operation skills in students through four of its skills-based modules over two years as these modules provide the best context for learning about the job role and responsibilities of process technicians: *Laboratory & Process Skills 1 (LPS1)* and *Laboratory & Process Skills 2 (LPS2)* in Year 1, and *Process Operation Skills 1 (POS1)* and *Process Operation Skills 2 (POS2)* in Year 2.

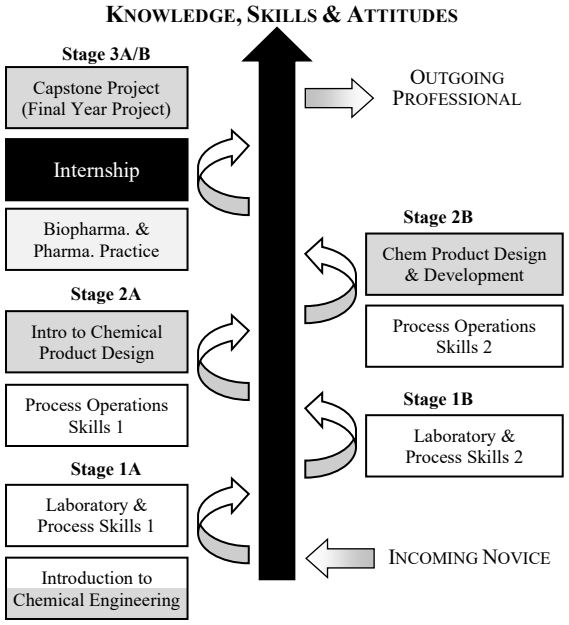


Figure 2. The DCHE Spiral Curriculum

The work shared here will be that done in *POS1*, taken by DCHE students in Year 2, Semester 1, and is a continuation of earlier effort to instill safety mindset in DCHE students, starting in *LPS1* where general workplace safety awareness is cultivated using Augmented Reality/ Virtual Reality training (Yang & Cheah, 2020) and laboratory safety was taught using Job Safety Analysis. In *LPS2*, students applied Job Safety Analysis and were exposed to Process Hazard Analysis when operating simple pilot plants. Such training comprises a blend of physical plants as well as virtual ones (Cheah, 2022; Cheah, 2021), designed based on CDIO Standard 7: Integrated Learning Experiences, where technical knowledge, skills and attitudes are all developed simultaneously using scenarios that mimic real-world work environment. Constructive alignment was used to check for attainment of learning outcomes using both formative and summative assessments.

Integrated Learning Experiences in POS1

POS1 has nine learning activities designed to provide students with a range of simulated real-world working environment of what process technicians do in their stipulated job role. Six of these learning activities will gradually develop students' abovementioned key competencies for process technicians as stipulated in the SSF for E&C Sector (Figure 3). The work shared here is carried out in Week 4 and is intended to support the later activity of preparing an equipment for maintenance in Week 6.

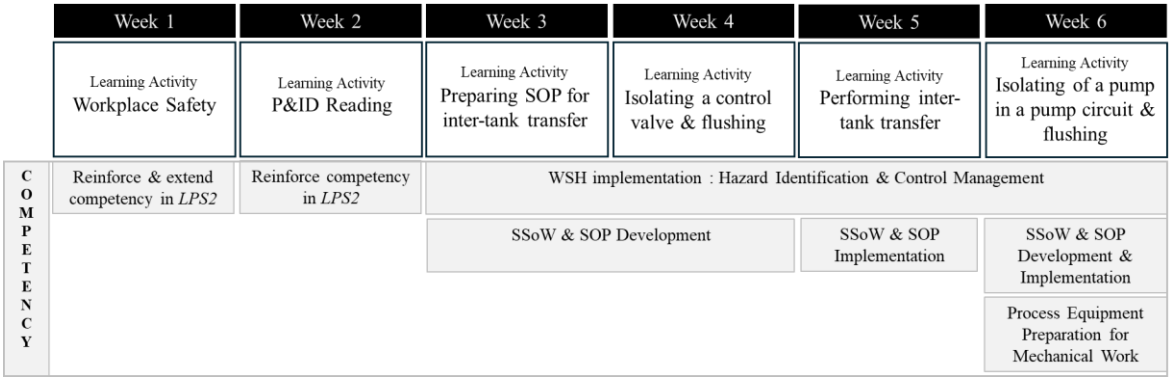


Figure 3. Selected Learning Activities in *POS1*

Since DCHE students do not have any real-world experience working in the chemical processing industry, learning activities to implement WSH and SSoW plans had to be slowly scaffolded into the module. Students' knowledge in *LPS2* from the previous semester on WSH awareness and Process Hazard Analysis were leveraged upon to progressively engaging them in activities with increasing complexity in *POS1*. In Week 4, isolation of a control valve and flushing of its associated piping were used as the basis to develop students' competency in preparing an equipment for maintenance. Choice of control valve was deliberate as it is commonly found in industry, and students had prior experience operating control valves in *LPS2*. Subsequently in Week 6, students had to demonstrate their ability to transfer the learning from control valve isolation to the preparation of a process equipment – in this case isolating a pump and its associated components (strainer, check valve and pipes), for flushing to remove any remnant chemicals in the pipes using an actual test skid in the workshop. Finally, students will submit a group report on their work done and a reflection journal of their learning experiences of the activities in Weeks 4 and 6.

To address the challenge of the large student cohort size (100-120 students per semester) which made it impractical to have many test skids in the limited workshop space which in turn reduces the number of hands-on practice students could have on the actual equipment, DCHE leveraged on technology and incorporated an Immersive Virtual Experiment (IVE) into the learning activity for Week 4. This approach is similar to that taken by Zhao *et al*. (2019) who used a virtual manufacturing shopfloor identical to the physical setup to overcome equipment and instructional hours limitations to teach safety, manufacturing equipment selection and operation.

Immersive Technology for Control Valve Isolation

The IVE is a digital learning package designed and developed in-house by SP. Since immersive technology provides a sense of immersion (Fracaro *et al.,* 2022; Lee *et al.,* 2013;

Lee *et al.,* 2012), when the technology is modelled after an actual site or equipment, users can gain familiarity through repeated virtual exploration of the site or equipment. This helps scaffold learning and allows faster transition to on-site work, or actual equipment operation (Fleury & Bondesan, 2024; Millard *et al.,* 2007; Zhao *et al.,* 2019). The IVE was therefore modelled after an actual control valve station commonly found in the chemical processing industry and on the actual test skid students will work on in Week 6 to provide familiarity and facilitate transition due to their lack of prior experience in carrying out mechanical work and difficulty in visualising the steps needed to plan and perform the work.

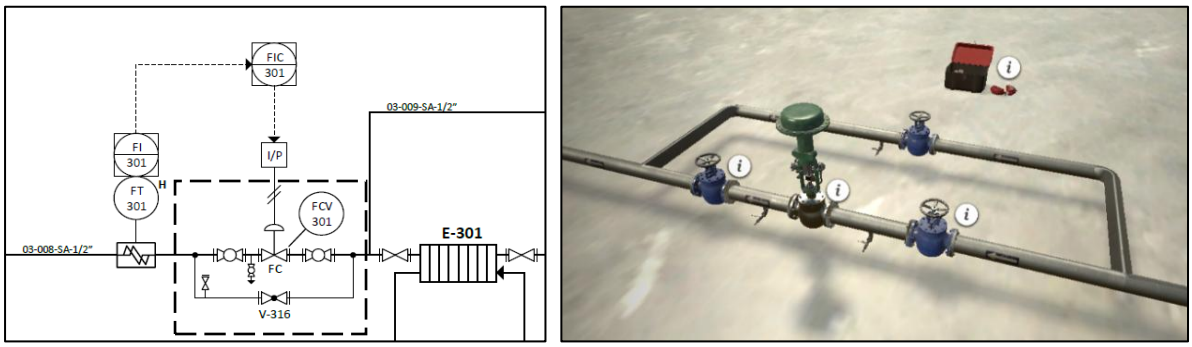


Figure 4. Schematic diagram of a typical control valve station enclosed in a rectangle (left) and the virtual control valve in the IVE (right)

The IVE consists of a 3D virtual representation of a control valve drawn to scale and offers active interaction between students and a section of the skid (Figure 4). It uses simple animations to allow students to interact with items within the environment and engage them in learning the content. Various hazardous scenarios were created to show consequences to students' actions using animations that would otherwise be impossible to replicate in real-life without serious consequences to safety. This enables experiential learning where students can better appreciate consequences of their actions, such as failure to undertake proper safe work practices, or overlooking a hazard during the risk assessment process, in a safe setting (Addison *et al.,* 2013; Fracaro *et al.,* 2022) thus increasing situational visualisation and awareness compared to traditional settings (Nakai, 2015; Nazir & Manca, 2015), all of which are useful when learning about health and safety (Millard *et al.,* 2007; Yang & Cheah, 2020) and operations (Norton *et al.,* 2008; Zhao *et al.,* 2019).

The prototype IVE was tested with 8 student volunteers from an earlier cohort who had completed *POS1*, and their input helped to refine the software package. The IVE was subsequently rolled out in Semester 1 Academic Year 2023/2024 to all six classes of students in the cohort reading *POS1*. Students will need to complete some of the following tasks in the IVE to demonstrate attainment of the desired learning outcomes:

- WSH Development and Implementation, Hazard Identification and Risk Control Management:
    1. Identify proper safety permits to use
    2. Barricade work area for restricted access
    3. Appropriate signage to warn of hazards present
    4. Select appropriate tools for the task on hand
- Process Equipment Preparation for Mechanical Work:
    1. Arrange steps in correct sequence according to the given SOP
    2. Identify suitable location to break flange

3. Coordination with Boardman in Control Room
4. Provision of secondary containment to reduce contamination of environment by residual process liquid during dismantling of piping

EVALUATION OF STUDENTS' LEARNING EXPERIENCE

A mixed-method survey was designed to evaluate the students' learning experience using the IVE in Week 4, and its effectiveness in helping them prepare for the activity in Week 6. A 5-point Likert-Scale was used where students were required to rate from "Strongly Disagree" to "Strongly Agree" on the following five questions:

1. The amount of content covered in the IVE was just nice.
2. I felt engaged (committed and motivated) when going through the IVE.
3. The simulations in the IVE have enabled me to better visualise the task at hand.
4. The knowledge checks in the IVE helped to check my understanding.
5. After doing the IVE, I feel more prepared to perform the practical on maintenance work in W319 (the workshop).

Students were then asked to estimate the amount of time they spent on the IVE, and finally to answer the following two open-ended questions:

6. Based on your response to Question 5, elaborate on your choice.
7. Suggest other ways(s) in which the IVE can help you be more prepared to perform the practical on maintenance work in W319 (the workshop).

The survey was administered to all students in the cohort reading *POS1*, and 88 students (83% of cohort) voluntarily completed the survey.

Discussion on the effectiveness of the IVE

87.5% of the respondents found the IVE content coverage sufficient for their learning of hazard identification and implementation of WSH and SSoW, and control valve isolation (Figure 5, left), with 92.0% of them completing it in 30 minutes or less (results not shown). Students felt that the timeframe was just right for them to remain engaged throughout to learn the content (87.5%; Figure 5, left). This suggests that even though use of immersive technology can enhance learning experiences and student engagement as reported by others (Colombo & Golzio, 2016; Huang *et al.,* 2016; Huang *et al.,* 2010), it is important to balance the duration of time needed and amount of effort needed to learn content using such technology. When students feel that they need to spend too much time to learn the content or too much effort to learn the content using the technology compared to traditional, which is often regarded as 'easier' due to familiarity, methods of, e.g. reading from notes or attending lectures, they may become disengaged or even surface undesirable behaviour such as introjected regulatory behaviour (Tan *et al.,* 2009). It is also important for students to be given explicit instructions on how to use the technology and/ or time to explore especially if the technology is unfamiliar to them.

Majority of students surveyed strongly agree or agree that the IVE was effective in preparing them to transfer what they learnt from the IVE in Week 4 and demonstrate it in another context - the activity carried out in Week 6 where they had to prepare a process equipment (a pump) in the workshop (W319) for maintenance (87.5%; Figure 5, right). This was attributed to the

interactivity and clarity of each step in the IVE as shared by one student: *"The IVE made it clear on what key tasks were involved in the maintenance work and how to perform the tasks"*.

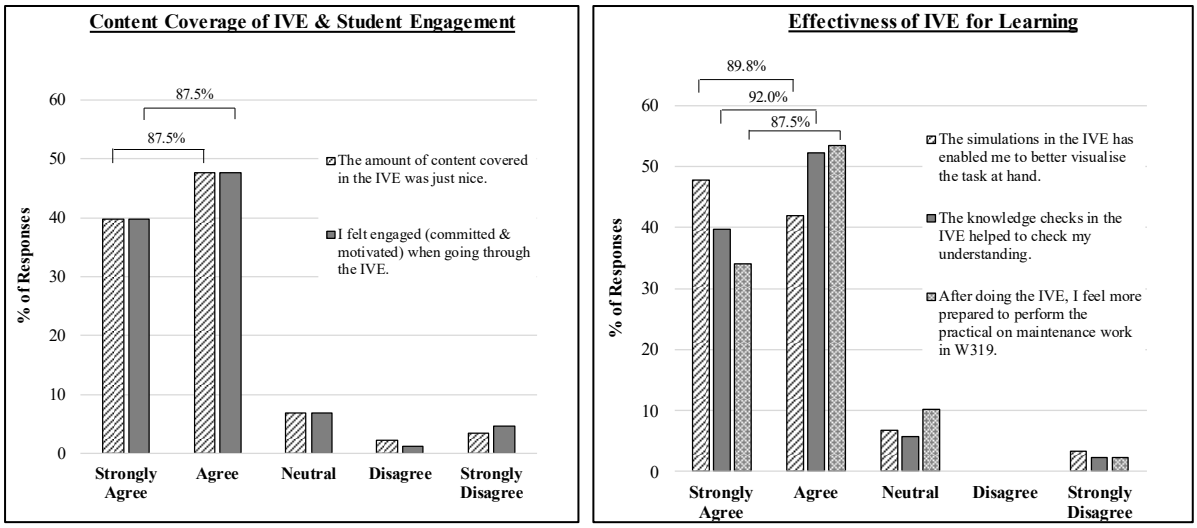


Figure 5. Content coverage of IVE and student engagement when using IVE (left) and effectiveness of IVE for learning (right)

A student opined that the IVE *"allowed me to know the different permits needed"* which is a key requirement when preparing equipment for maintenance based on the SSoW framework that students had to carry out in Week 6. Nonetheless, a few students had some reservations (2.3% disagree or strongly disagree; Figure 5, right) on their preparedness to demonstrate transfer and application of knowledge on the actual equipment in Week 6. This lack of confidence was not surprising as this was the first instance students had to perform mechanical work. One student shared: *"I felt mostly prepared to perform isolation, but not fully since there are differences in doing isolation for a control valve and a pump"*, suggesting the different context that he/she had to apply the knowledge led to the reservation and not the insufficient knowledge of how to go about doing so.

The overall positive sentiments on the effectiveness of IVE for learning, and engagement that students felt when using the IVE can be attributed to three factors: the knowledge checks, the interactivity and the realistic visuals/ animations. 92.0% of students strongly agreed or agreed that the knowledge checks provided insights to how well they understood the IVE content and the specific section(s) they may need to re-visit (Figure 5, right) to meet the learning outcomes. Through the interactivity and realism provided in the IVE, 89.8% of students strongly agree or agree they were able to better visualise the planning and execution processes needed to prepare an equipment for maintenance and developing simultaneously the safety mindset needed (Figure 5, right) even though they had no prior experience in carrying out such mechanical work. They were able to identify the hazards and measures needed to mitigate or control these hazards. This was followed by identifying the permits needed in the SSoW and finally sequencing the steps that will lead to the isolation of the control valve into an SOP. Consequences were also shown if the SOP was not followed and/ or students choose to take an action that will result in an unsafe or hazardous condition. These were succinctly articulated by two students: *"The IVE gave me a better idea on how to perform practical 6 as it is visually enriching, and it helped to guide me through the different steps that needed to be taken during*

the isolation and preparation of the equipment for maintenance.", and "It helped me to visualise what I have to do with my team for maintenance work. For example, which isolation valves to close first."

These positive survey findings show that the IVE was useful to develop in students the desired safety mindset alongside the key competencies required by Process Technicians as stipulated in the SSF for E&C sector (Figure 3) similar to that reported by Colombo & Golzio (2016) who found that immersive technology when used for training in the process industry enabled more learning compared to traditional didactic training.

Discussion on students' reflections on learning to prepare process equipment for maintenance and safety mindset

In students' reflection journals submitted after both learning activities in Weeks 4 and 6 were completed, the most frequently cited skills that were acquired were (1) construction of utility tie-in lines which are needed for flushing after equipment isolation, (2) application of the correct procedures (Lock Out, Tag Out; LOTO) to ensure that equipment was properly isolated before maintenance, (3) proper handling and usage of tools needed for equipment isolation and (4) selection of correct location and steps needed to break flanges safely when isolating equipment (Figure 6). These technical skills are necessary to develop competency in preparing process equipment for maintenance work alongside with a safety mindset. Students also cited top non-generic skills that they acquired and were highly important to ensure safety and work efficiency such as (1) planning of work and preparation of required documentations such as SOP, permits etc, (2) communication and teamwork, (3) leadership, and (4) adaptability and problem-solving ability. In one entry, a student reflected that: *"…, I learnt that the planning stage is crucial in the context of preparing equipment or a system for shutdown for several reasons. Firstly, the biggest point of concern during any plant activity: safety. Proper planning allows for a comprehensive assessment of potential risks, identification of safety procedures, and implementation of necessary precautions. This includes ensuring that appropriate isolation procedures are followed, hazardous materials are handled safely, and potential safety hazards are mitigated."*

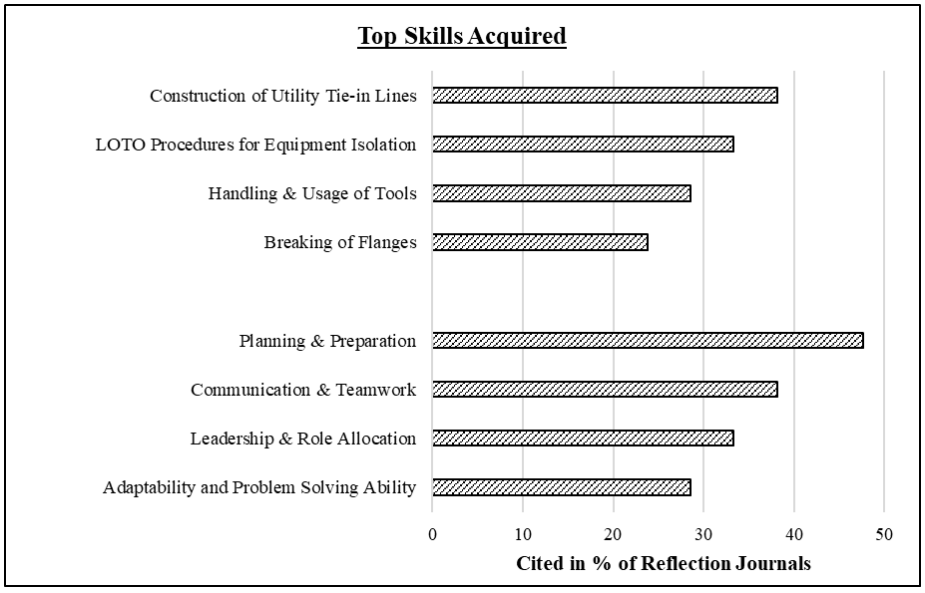


Figure 6. Top skills acquired from learning activities in Weeks 4 and 6

During the actual hands-on activity where students performed pump isolation in Week 6, all students experienced leakages (of various magnitudes) of the residual process liquid during flushing due to poor tightening of flanges and fittings. Many students were caught off-guard as leakages during flushing were not modelled in the IVE, and they did not realise the importance of proper flange tightening techniques and the resultant consequences even though the lecturer had gone through a briefing prior to the start of the activity. Although the process liquid was only water, it can be a hazardous liquid in real-life industry and consequences will be far more severe. Students also had to adapt to the unexpected unsafe situation that had developed and perform problem solving on the spot to resolve the leakages and continue with the learning activity. As such, this incident left a lasting impression on many students (hence, relatively high number of journal entries – 42.9% cited leakage prevention as important), and helped reinforced the need to perform thorough hazard identification and risk control management. In their reflection journals, students were able to highlight the importance of on-site verification in ensuring safety and adherence to SSoW and WSH systems as it allows checking of the accuracy of SOP developed, identification of hazards that may otherwise been missed out during planning stages and also inspection of any non-compliance to regulatory and procedural requirements. These reflections suggest that students had acquired the key competencies needed to prepare process equipment for mechanical works safely as required by the SSF for the E&C sector for process technicians.

CONCLUSION

The experience of using an IVE to facilitate training of students to prepare equipment for maintenance with a safety mindset, which are key competencies for process technicians in the E&C sector, was shared here. Survey findings and reflection journal entries from the students' experiences in using the IVE to learn WSH, and SSoW and SOP implementation for control valve isolation, and subsequently to transfer this learning to that of pump isolation and maintenance was positive. The benefits of the IVE in teaching and learning of these skills can be clearly summarised by one student's sharing *"It helped visualise an otherwise difficult area of study to imagine without seeing firsthand examples and thus assisted in understanding of the process as well as the tasks we are supposed to do".*

This is very encouraging, given that the realism of the visuals and interactivity to actual operations in immersive digital technology (Nazir & Manca, 2015) and the ability to allow for repeated practice make such technology a natural fit for teaching and learning of knowledge and skills for industries such as chemical process when there is a need to transfer the acquired knowledge or skills readily to actual equipment or processes or to replicate conditions for training that would otherwise be unsafe or impossible to carry out in real life (Addison *et al.,* 2013; Fracaro *et al.,* 2022; Koskela *et al.,* 2005; Millard *et al.,* 2007; Norton *et al.,* 2008; Zhao *et al.,* 2019). DCHE is reviewing and purposefully designing more activities with greater complexity that leverage on similar technology such as to make use of a digital twin of an actual pilot plant to let students operate a pilot plant under different scenarios such as a sudden plant upset and learn how to respond in these situations with a safety mindset. These activities will facilitate further development of key competencies alongside with the safety mindset to the desired proficiency level as required by process technicians in the E&C sector.

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COMMERCIAL PILOT EDUCATION: ALIGNING EASA 100 KSA WITH CDIO STANDARDS

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ABSTRACT

This paper examines the alignment of the European Aviation Safety Agency (EASA) 100 Knowledge, Skills, and Attitude (KSA) framework with the Conceive-Design-Implement-Operate (CDIO) standards and syllabus. The EASA 100 KSA introduces a competency-based approach to pilot training that emphasises both technical skills and those traditionally classified as “non-technical", such as critical thinking, decision making, situational awareness and crew resource management. However, in line with the CDIO standards, these competences should not be considered as separate components, but as interconnected skills that emerge from the technical context and operational practice. In pilot education, it is essential to combine technical expertise with the ability to communicate effectively and make informed decisions, and to promote synergies between the different competency areas to ensure holistic development of future aviation professionals. Building on this integrated approach, the EASA 100 KSA framework represents a significant shift from traditional flight hour-centered training to a holistic methodology that meets the modern needs of the aviation industry. The study finds substantial alignment between the EASA framework and CDIO principles, particularly in fostering skills such as teamwork, problem-solving, and hands-on learning. The innovative aspect of this work lies in bridging aviation and engineering education frameworks, showing the adaptability of CDIO principles in enhancing pilot training standards. This research contributes to the evolution of aviation education, emphasizing a balanced approach to competency development that equips professionals for the complexities of modern aviation.

KEYWORDS

Commercial pilot education, Aviation education, EASA 100 KSA Framework, CDIO Syllabus, Standards 2, 3, 7.

INTRODUCTION

The aviation industry faces the challenge of adequately preparing pilots for the increasingly complex demands of modern flight operations. Traditional pilot training, which relies heavily on flight hours and memorization, often fails to develop comprehensive skills that are essential for safety and efficiency. This paper examines the European Aviation Safety Agency's (EASA) 100 Knowledge, Skills and Attitudes (KSA) framework and compares it to the Conceive-Design-Implement-Operate (CDIO) standards used in engineering education. The aim is to address the gap in aviation training by exploring methods that incorporate both technical and non-technical skills into pilot education.

The EASA 100 KSA (Annex II to ED Decision 2018-001-R.pdf) is a framework as an innovative model for competency-based aviation training. In contrast to traditional methods, it emphasises a holistic approach covering four areas: Aeronautical Knowledge, Practical Skills, Airmanship, and Human Factors. The validity of the framework is supported by its rigorous, evidence-based structure and its implementation of both formative and summative assessments. The results show an improvement in the holistic preparation of commercial pilots that is consistent with global safety standards and technological advances. Compared to previous methods, this model enhances both technical proficiency and non-technical competences. However, limitations include challenges in implementation due to resource constraints and the risk of overemphasizing broad competencies at the expense of technical expertise. Addressing these issues may require adjustments in curriculum design and resource allocation. Comparison with the CDIO standards shows the similarities in emphasizing the integration of theoretical knowledge with practical application, teamwork and critical thinking. The research highlights potential areas where aviation education can be aligned with engineering education methods to improve pilot readiness.

This research underscores the need for an interdisciplinary, competency-based approach to pilot education. The alignment between EASA 100 KSA and CDIO framework provides opportunities for mutual reinforcement to improve both aviation and engineering education. Future research could focus on refining competency profiles, evaluating the long-term impact of such training on operational safety and exploring cross-industry applications. The findings argue in favor of continuously adapting curricula to meet evolving technological and operational demands in aviation. By aligning with CDIO standards, this approach promises to improve both safety and efficiency in aviation and pave the way for future innovation in professional training methods.

EASA 100 KSA FRAMEWORK

Valdés et al (2017) emphasize that the European aeronautics industry, a major economic driver, is projected to double in economic output and employment by 2030, necessitating a significant investment in high-quality vocational education and training to address the growing demand for skilled professionals. In this context, education, certification, and experience are crucial in developing the knowledge, skills, and abilities required to meet the evolving needs of the industry. They are interconnected, build on each other and contribute to an individual's overall competence and expertise. Education provides the basic knowledge and theoretical understanding necessary for the development of KSAs. It serves as a foundation for future learning and skills development. Formal education programmes provide structured learning experiences that introduce key concepts, principles and frameworks relevant to a specific field. Watkins et al (2016) mention that education forms the foundation on which experience is built. Experience, especially practical experience, plays a crucial role in enabling individuals to apply

their knowledge and develop specific skills. It provides opportunities to learn by doing, to solve real-world problems and develop abilities, emphasizing the importance of experience in building the foundation laid by education. Ford and Schmidt (2000) also emphasize the significance of experience in developing expertise, particularly in critical areas such as emergency response. Certification validates an individual's KSAs and provides external verification of their competence. It signifies that an individual has met specific standards and has the necessary knowledge and skills for a particular role or profession. Baird & Brooks, (1988) explain that certification implies competence and is often based on a combination of formal training and experience. Watkins et al (2016) state that certificate holders in their study rated their KSAs higher than non-certificate holders. In some professions, certification may be a requirement for employment or career advancement. The development of comprehensive competences that go beyond technical knowledge and skills plays a decisive role. These include emotional, social and cognitive intelligence competencies that are essential for success in the modern, dynamic workplace. (Bonesso et al., 2020) (Sari et al., 2021)

According to Glassman et al (2015), the three most important factors aviation managers consider when hiring new team members are education, certification and experience. They found that education is considered essential for new hires and upward mobility, especially in management roles. Certification is critical for specific career fields in aviation, such as aircraft operations, maintenance or servicing aircraft. Finally, experience, particularly with a military background, is highly valued, especially when dealing with in-flight emergencies. Employee certification and training are key factors that influence an employee's knowledge, skills and abilities. Recruiters tend to look for candidates with a mix of these characteristics when making hiring decisions. It is important to recognize that these KSAs are not only important for individual productivity, but also for effective teamwork.

Building on this, the EASA 100 KSAs framework used for the training and assessment of commercial pilots is closely aligned with these hiring priorities. It is divided into four main categories - Aeronautical Knowledge, Practical Skill, Airmanship, and Human Factors — and provides a structured approach to developing a wide range of competences including technical proficiency, decision-making, situational awareness and crew resource management.

To gain a better insight into these competences in the context of the 100 KSAs, it is important to examine the development of training principles in aviation over the generations. In the field of aviation training, Kearns (2016) examines how training methods have evolved over three different generations. These generations illustrate the transition from traditional, manual training approaches to more sophisticated, technology-driven methods, with each phase requiring a unique set of KSAs:

- First Generation: Apprenticeship - This era focused on basic flight training through direct supervision by experienced pilots. Training consisted of classroom instruction and in-flight training, with an emphasis on mastering specific maneuvers and performance standards. The training model allowed for hands-on learning and the transfer of knowledge and skills from experienced pilots to aspiring aviators. This corresponds to the Aeronautical Knowledge and Practical Skill components of the EASA 100 KSA concept.
- Second generation: Simulation - The invention of the Link Trainer in 1929 marked the beginning of flight simulation. This enabled weather-independent training and expanded the scope of training to include instrument and system operations. While simulation became a key component, the training model of classroom instruction and in-flight training remained. The focus remained on achieving performance standards, with the added benefit of improving technical proficiency through simulation-based

exercises. The Practical Skill aspect of 100 KSA is further developed through the use of simulations.

- Third generation: Safety - This generation arose from concerns about human error in aviation accidents. Crew Resource Management (CRM) training emerged, emphasizing the effective use of all available resources for safe and efficient flight operations. This shift brought a new focus on non-technical skills such as communication, teamwork and decision-making alongside traditional flight training. The emphasis on CRM aimed to enhance the overall safety and efficiency of flight operations by utilizing the collective expertise and collaboration of the flight crew. This is in line with the *Airmanship and Human Factors* components of the 100 KSA concept.

This holistic approach goes beyond technical proficiency and emphasises the importance of critical thinking, decision-making, situational awareness and crew resource management. By defining these specific KSAs, EASA has provided a robust and evidence-based foundation for ensuring that commercial pilots possess the necessary capabilities to handle the complex and dynamic challenges of modern aviation.

In this sense, the implementation of the 100 KSA framework marks a shift in the industry's approach to pilot training and assessment, moving away from a narrow, quantitative focus towards a more qualitative assessment of pilot competence. This has the potential to increase flight safety and overall operational efficiency. As such, it is a valuable contribution to ongoing efforts to improve the quality and effectiveness of commercial pilot education.

EASA's technical review of the theoretical knowledge syllabi, learning objectives, and examination procedures for air transport pilot licence, multi-crew pilot licence, commercial pilot licence and instrument ratings (RPRO, 2016) propose several important requirements for pilot training and knowledge. The learning objectives are updated to reflect modern cockpit practises and industry needs, and to enhance pilots' core competences and decision-making abilities. New learning objectives are introduced under 100 KSA, to be assessed by Approved Training Organisations (ATO) rather than through formal examinations. The document also recommends a process to regularly review and update these learning objectives to keep pace with evolving safety threats, technological advances and operational practices. The changes proposed will impact on pilot training in several ways, with a focus on updating the learning objectives to better align with the current needs of the aviation industry.

CDIO STANDARDS AND ALIGNMENT WITH EASA 100 KSA

The CDIO initiative is a global framework for engineering education that provides a comprehensive framework for the development of students' professional competences. While the CDIO standards are primarily focused on the broader field of engineering, they also provide valuable insights and principles that can be applied to the context of commercial pilot education. The CDIO standards emphasize a holistic approach to education that encompasses the entire lifecycle of a product or system - Conceiving, Designing, Implementing, and Operating. This aligns closely with the EASA 100 KSA concept, which focuses on developing a comprehensive set of knowledge, skills and attitudes required for safe and effective pilot operations.

A key area of alignment is the CDIO standard for personal and professional skills, which includes competencies such as critical thinking, problem solving and teamwork. These skills are also emphasised within the EASA 100 KSA, particularly in the Airmanship and Human Factors categories. (Du & Zhu, 2022)

The CDIO's emphasis on hands-on, active learning and the integration of theoretical and practical knowledge aligns with EASA's focus on the development of practical skills and the application of aeronautical knowledge.

This synergy between the two approaches provides valuable insights for improving the effectiveness of commercial pilot education. The alignment between the CDIO and EASA frameworks suggests that the adoption of a similar holistic, competency-based approach could significantly enhance the effectiveness of commercial pilot training programmes. By incorporating the development of both technical and non-technical skills, such as communication, decision making and resource management, aspiring pilots would be better equipped to meet the complex and dynamic challenges of the modern aviation industry.

As valuable as the opportunities for greater integration and mutual reinforcement of these two frameworks are, there are also potential drawbacks to consider. The holistic approach emphasized by the CDIO framework aligns well with EASA's focus on comprehensive pilot competencies. However, there is a risk that overly broad training could weaken the essential technical skills required for safe flight operations, even though the CDIO's emphasis on personal and professional skills such as communication and teamwork remains critical for pilots navigating the complex aviation environment. It is crucial to maintain a balance between developing these non-technical competencies and ensuring that pilots possess a deep understanding of aircraft systems, aerodynamics and other core technical knowledge. Finding the right balance between theoretical instruction and practical application will be an important consideration. Ultimately, while the CDIO framework provides a valuable reference point, the specific design and implementation of commercial pilot education programmes must be carefully tailored to the unique needs and constraints of the aviation industry. A nuanced approach that preserves essential technical expertise while meaningfully incorporating non-technical competencies may be the most effective path forward.

However, it is crucial to strike a balance between the holistic competency development advocated by the CDIO framework and the need to maintain the technical expertise required for safe flight operations. The integration of theoretical and practical learning advocated by the CDIO standards may also present challenges in the time and resource constrained environment of commercial pilot training. (Brink et al., 2020)

The US Naval Academy's approach to the CDIO curriculum, described in (Crawley et al., 2014), focuses on providing a framework for practical, hands-on engineering education. The Department of Aerospace Engineering took this approach to go beyond theoretical "paper designs" and train graduates capable of operating complex systems, which is the operational focus of the Navy and Marine Corps. They wanted to create a programme where midshipmen could conceive, design, implement and operate complex aerospace systems in a team-based environment. This approach was also driven by a desire to meet ABET accreditation standards and benefit from the experience of other universities that were implementing CDIO.

Table 1 illustrates the alignment between the EASA 100 KSA framework, which defines the essential Knowledge, Skills, and Attitudes for commercial pilot training, and the CDIO standards and syllabus. Both frameworks emphasize holistic, competency-based learning that integrates technical and non-technical skills.

Table 1. Alignment of EASA 100 KSA Framework with CDIO Standards

EASA 100 KSA Category	Description	Aligned CDIO Standards	Explanation of Alignment	Aligned CDIO Syllabus	Explanation of Alignment
Aeronautical Knowledge	Foundational knowledge such as flight theory, regulations, and systems.	**2 (Learning Outcomes)**, **3 (Integrated Curriculum)**	CDIO ensures detailed learning outcomes and integrated courses that build foundational knowledge crucial for aeronautical expertise.	**1.2 (Core Engineering Fundamental Knowledge); 1.3 (Advanced Engineering Fundamental Knowledge, Methods and Tools)**	The CDIO Syllabus emphasizes disciplinary knowledge, forming the theoretical foundation of pilot education.
Practical Skill	Technical mastery, simulator exercises, and real-world flight performance.	**6 (Engineering Workspaces)**	Simulator-based training and in-flight exercises correspond to CDIO's emphasis on hands-on, iterative design and implement phases.	**2.2 (Experimentation, Investigation and Knowledge Discovery); 2.3 (System Thinking)**	Hands-on training and iterative flight exercises align with CDIO's focus on practical application and systems thinking.
Airmanship	Leadership, teamwork, and operational responsibility in aviation.	**7 (Integrated Learning Experiences)**, **8 (Active Learning)**	Integrated learning enhances decision-making and teamwork through CRM principles; active learning fosters real-world scenario engagement.	**3.1 (Working in teams), 3.2 (Communication)**	CDIO highlights the role of teamwork and communication in professional practice, essential in crew resource management (CRM).
Human Factors	Skills such as communication, decision-making, and situational awareness.	**1 (Context)**, **9 (Enhancement of Faculty Competence)**, **10 (Teaching Competence)**	Human factors align with CDIO's focus on real-world system operations and faculty development in teaching interpersonal and situational awareness skills.	**2.4.4 (Creative Thinking), 2.4.5 (Critical Thinking)**	Critical thinking and situational awareness are integral to safe flight operations, as emphasized in CDIO.
Continuous Improvement	Regular updates to pilot training to reflect industry advancements.	**11 (Learning Assessment)**, **12 (Program Evaluation)**	Both frameworks emphasize iterative assessment and evolution of training programs to adapt to new challenges and improve effectiveness.	**2.4.7 (Learning Agility, Lifelong Learning and Educating)**	Both frameworks stress iterative learning and adaptation to technological and operational changes.
Holistic Competency Development	Emphasis on integrating technical and other skills for comprehensive pilot training.	**2 (Learning Outcomes)**, **3 (Integrated Curriculum)**, **7 (Integrated Learning Experiences)**	The holistic integration of theoretical, practical, and interpersonal skills aligns with CDIO's multidimensional learning outcomes and structured interdisciplinary approach.	**3.1 (Working in teams); 3.2 (Communication), 4.1 (External, Societal and Environmental Context)**	CDIO emphasizes the integration of technical and other skills, essential for comprehensive pilot training.

Each row highlights how specific EASA KSA categories relate to one or more CDIO standards. This alignment shows synergies in areas such as foundational knowledge, practical skills development, teamwork and continuous improvement. By integrating CDIO principles into aviation training, pilot education programs can benefit from structured, practical and interdisciplinary approaches that improve both technical proficiency and operational safety. In the education of commercial pilots, which clearly requires an engineering foundation, the CDIO Syllabus emphasises the importance of preparing students for professional practice rather than serving as a rigorous process model. While there are structured phases in pilot training, the CDIO framework emphasises the need for an integrated approach that develops both technical and professional competencies in real-world contexts. Understanding flight principles and regulations, planning flights and procedures, executing flight maneuvers and managing aircraft systems are not just sequential steps, but interconnected aspects of a pilot's professional role. Commercial pilot training often emphasises scenario-based training and simulator work to allow students to develop their operational skills in a controlled environment. Also, the emphasis on teamwork in the CDIO curriculum aligns with the principles of Crew Resource Management (CRM) in commercial aviation, as highlighted in (Du & Zhu, 2022). CRM training, which improves communication, coordination and decision-making within a cockpit crew, is an example of how professional skills are deeply embedded in the technical and operational aspects of aviation.

ADVANCING PILOT EDUCATION AND ALIGNING WITH CDIO STANDARDS AT THE UNIVERSITY OF ZAGREB

The Department of Aeronautics at the University of Zagreb (Faculty of Transport and Traffic Sciences), Croatia, has incorporated the EASA 100 KSA framework into its curriculum, aligning its teaching approaches with evolving competency standards in the aviation industry. Key competencies that are developed include communication, leadership and teamwork, problem solving and decision making, situational awareness, workload management, application of knowledge, threats and error management, and mental math skills that are critical for flight safety. To achieve these goals, the Department applies a structured, evidence-based approach to education and evaluation. This includes continuous assessment of both technical and non-technical skills using a 5-point grading system and multiple assessments. Student pilots undergo at least three mandatory assessments during their flight training, which are integrated into the study programme. The first, a formative assessment, identifies learning gaps and encourages improvement through targeted feedback and reflection. Summative assessments, conducted in the middle of the flight training and at the end of the theoretical lessons, evaluate competence levels against predefined indicators and ensure that they are prepared for professional requirements. The use of structured debriefing and feedback loops supports the continuous improvement and self-awareness in student pilots. To further improve practical skills, mental maths tests and assessments are conducted, focusing on flight-critical calculations where students must achieve a minimum accuracy of 75 per cent. The study programme spans three years (six semesters), with three mandatory assessments conducted two months to ensure continuous progress and competence development. This comprehensive integration of the EASA 100 KSA framework is in line with the CDIO concept and ensures that graduates of the University of Zagreb's Department of Aeronautics are equipped with the necessary competences to be competitive in the dynamic and demanding aviation industry. The self-assessment of the study programme shows a high level of alignment with CDIO standards but also indicates areas for improvement. In particular, the programme is highly aligned with the standards in learning outcomes, integrated curriculum and integrated learning experiences. The programme is designed in accordance with the

regulations and standards of the European Aviation Safety Agency, which are listed in CDIO Standard 2, among others. The implementation of the learning outcomes is prescribed in detail and is regularly reviewed to fulfil the legal requirements. All national standards are applied in accordance with the Croatian and European qualification frameworks. Within the disciplinary courses there is an explicit link between the content and the learning outcomes. Students are expected to achieve a comprehensive set of learning outcomes that are consistent with the objectives of the programme. Compliance with the European Aviation Safety Agency regulations and the Croatian and European Qualifications Framework can be cited as evidence of well-defined learning outcomes. Furthermore, the programme emphasises the link between disciplinary courses and learning outcomes, as well as the use of certified laboratories where students work individually with instructors. However, the self-assessment also shows lower scores for other standards. For Standard 6, the programme uses certified labs but admits that there is a lack of formal assessment of these spaces. Similarly, for Standard 7, although the programme claims a high level of integration in learning experiences, it notes a lack of regular evaluation and revision of courses in this aspect. The self-assessment of Standard 4 reflects a lack of learning flexibility as the focus is on the design and implementation of processes within basic design and implementation projects as part of the planned activities of the relevant aviation authorities. Explicit planning for professional skills development could also be improved according to Standard 3. Finally, for Standard 1, the programme refers to an early stage of application, suggesting that full implementation of CDIO principles is still a work in progress.

CONCLUSION

This paper examines the European Aviation Safety Agency (EASA) 100 Knowledge, Skills, and Attitude (KSA) framework and its alignment with the Conceive-Design-Implement-Operate (CDIO) standards. The EASA 100 KSA introduces a competency-based approach to commercial pilot education, emphasizing technical and non-technical competencies, including critical thinking, decision-making, situational awareness, and crew resource management. This framework represents a significant shift from traditional flight-hour-centric training to a holistic methodology addressing the modern demands of the aviation industry. The study finds substantial alignment between the EASA framework and CDIO principles, particularly in fostering skills such as teamwork, problem-solving, and hands-on learning. The innovative aspect of this work lies in bridging aviation and engineering education frameworks, showing the adaptability of CDIO principles in enhancing pilot training standards. This cross-disciplinary perspective underscores the broader applicability of competency-based approaches across industries. The validity of the EASA 100 KSA framework is supported by its rigorous, evidence-based structure and its implementation of both formative and summative assessments. Analyses conducted at the University of Zagreb's Department of Aeronautics over the past five years demonstrate an improvement in the holistic preparedness of pilots, aligning with global safety standards and technological advancements. Compared to prior methods, this model enhances both technical proficiency and non-technical competencies (BAA Training, 2021). However, limitations include challenges in implementation due to resource constraints and the risk of overemphasizing broad competencies at the expense of technical expertise. Addressing these issues may require adjustments in curriculum design and resource allocation. Future work should focus on fine-tuning the integration of technical and non-technical skills in training programs, investigating long-term impacts on safety and operational efficiency, and exploring adaptations for other high-stakes professions. This research contributes to the evolution of aviation education, emphasizing a balanced approach to competency development that equips professionals for the complexities of modern aviation.

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EMBEDDING ETHICS AND PROFESSIONAL RESPONSIBILITY IN ENGINEERING EDUCATION: PREPARING FUTURE ENGINEERS FOR INDUSTRY 5.0

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ABSTRACT

Engineering education is undergoing a transformative shift to prepare students for the challenges of the 21st century, particularly as the world embraces the principles of Industry 5.0. This new industrial paradigm emphasizes human-centric innovation, ethical practices, and sustainability, placing ethics and professional responsibility at the forefront of engineering education. These values are essential for equipping future engineers with the skills and judgment to address global challenges such as climate change, equitable access to technology, and the responsible use of artificial intelligence. This paper explores the integration of ethics and professional responsibility into the engineering curricula through the CDIO (Conceive-Design-Implement-Operate) framework. By embedding these principles at every stage of the engineering lifecycle, the CDIO approach ensures that students not only gain technical competence but also develop the moral and professional accountability required to navigate complex, real-world challenges. The paper also highlights the role of interdisciplinary collaboration, experiential learning, and research-driven education in fostering ethical awareness. Additionally, the paper examines how partnerships with industry and the adoption of innovative teaching methodologies—such as problem-based learning, role-playing, and case studies—can further reinforce these principles. It underscores the importance of assessment strategies that evaluate students' ethical decision-making skills and professional responsibility. Aligning with the theme of "Forging Connections: Synergies for a Sustainable Future," this paper outlines actionable strategies for educators and institutions to prepare engineers who are technically proficient, ethically grounded, and capable of contributing to sustainable and human-centered innovation. By bridging education, research, and industry, this approach paves the way for a new generation of engineers ready to lead in the era of Industry 5.0.

KEYWORDS

Ethical competence, Engineering education, Sustainability, Industry 5.0, CDIO Framework, Ethical Decision-Making, "Standards: 1-6, 8, 10".

INTRODUCTION

Engineering plays a transformative role in addressing critical global challenges, such as climate change, resource scarcity, and social inequalities (Mihelcic et al., 2017). In this era of rapid technological advancement, engineers must not only possess technical proficiency but also demonstrate ethical integrity and professional responsibility (Van de Poel & Royakkers, 2023). These qualities are essential to ensure that engineering innovations contribute to a sustainable, equitable, and human-centered future (Longo et al., 2020). The emergence of Industry 5.0 underscores the importance of ethical and human-centric practices in engineering. Unlike Industry 4.0, which focused on automation and efficiency, Industry 5.0 emphasizes the synergy between advanced technologies and societal well-being (Ghobakhloo et al., 2024). Engineers are expected to design systems that prioritize inclusivity, sustainability, and ethical governance, making it imperative for engineering education to adapt accordingly. Future engineers must navigate complex ethical dilemmas, such as ensuring transparency in artificial intelligence, addressing environmental trade-offs in energy systems, and balancing automation with workforce stability. Ethics in engineering education encompasses principles of integrity, accountability, and fairness, while professional responsibility involves a commitment to societal welfare, environmental stewardship, and equitable resource distribution. To address these imperatives, educational frameworks must evolve to integrate ethics as a core component. This integration aligns with the values of Industry 5.0 and prepares engineers to address global challenges responsibly. The CDIO (Conceive-Design-Implement-Operate) framework provides a robust platform for embedding ethics and professional responsibility into engineering curricula (Tobias & Alvarez, 2024). This framework emphasizes real-world application, interdisciplinary collaboration, and continuous improvement, making it ideal for cultivating ethical awareness and professional accountability. This paper examines approaches to integrating ethics and professional responsibility into engineering curricula within the context of Industry 5.0. It explores how the CDIO (Conceive-Design-Implement-Operate) framework can serve as a foundation for embedding ethical considerations into engineering education. Rather than presenting a single, comprehensive framework, the paper discusses key challenges, innovative teaching methodologies, and strategies for fostering ethical awareness through research and industry collaboration. The following sections will analyze current trends in engineering ethics education, review best practices, and propose actionable recommendations for strengthening ethical and professional responsibility in engineering programs.

INTEGRATING ETHICS IN CDIO: INNOVATIVE APPROACHES TO TEACHING ETHICAL COMPETENCE

The CDIO framework provides a structured approach to embedding ethics at every stage of the engineering process (see Figure 1). During the Conceive phase, students analyze societal needs and ethical considerations when defining problems. The Design phase focuses on creating solutions that prioritize safety, inclusivity, and sustainability. In the Implement phase, ethical practices are emphasized through adherence to standards and transparent deployment of solutions. Finally, the Operate phase highlights the importance of accountability and continuous improvement in maintaining systems. By aligning the CDIO framework with the principles of Industry 5.0, educators can prepare future engineers to be not only technically skilled but also ethically aware and socially responsible (Al-Juboori and Noonan, 2024).

To further strengthen ethics within the CDIO framework, several strategies can be employed:

1. Interdisciplinary Collaboration. Engaging students with experts from law, sociology, and philosophy broadens their ethical perspectives. This approach encourages students to view engineering challenges through a multi-dimensional lens, enriching their understanding of complex moral dilemmas (Pavlidou et al., 2021).
2. Role-Playing and Simulations. Practical scenarios replicating ethical challenges, such as addressing bias in AI systems or weighing environmental trade-offs in large-scale projects (Patel, 2024), allow students to develop hands-on experience in ethical decision-making.
3. Mentorship Programs. Pairing students with industry professionals provides insight into real-world ethical challenges. Mentorship discussions about balancing innovation with accountability prepare students for the complexities of professional engineering practice (Hamilton & Brabbit, 2007).

Integrating ethics within the CDIO framework directly supports the human-centric and sustainable values of Industry 5.0. This approach cultivates empathy, social awareness, and accountability, ensuring that students develop innovative solutions that prioritize equity and sustainability. Furthermore, aligning ethics integration with institutional goals, such as producing socially responsible graduates, enhances academic reputation and accreditation compliance (Glendinning, 2022).

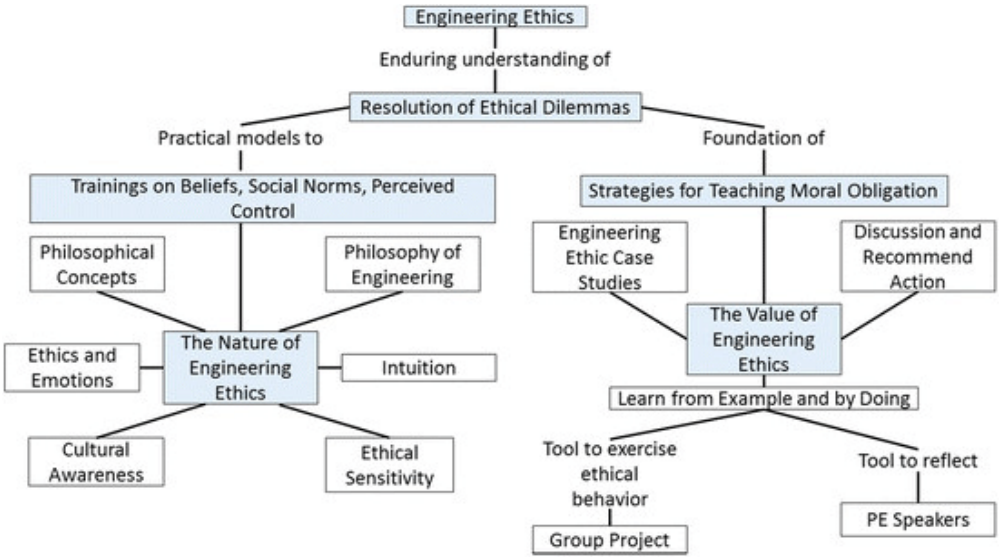


Figure 1. The concept of engineering ethics in engineering education

Engineering education must incorporate ethics and professional responsibility through engaging and forward-thinking approaches that seamlessly fit within the CDIO framework. By embedding ethics into every stage of the engineering process, these methodologies equip students with the skills to navigate the complex ethical challenges of Industry 5.0, which emphasizes human-centric innovation, sustainability, and societal well-being. Furthermore, these approaches prepare students for lifelong ethical leadership, ensuring that they not only succeed in academic settings but also contribute responsibly to global progress (Belefeldt et al., 2018).

- *Case-based learning* immerses students in real-world ethical scenarios (Yadav et al., 2014), such as AI bias in hiring systems, sharpening critical thinking and problem-solving skills. Within the CDIO framework, it is effective during the Conceive stage, aligning ethical decision-making with Industry 5.0's focus on fairness and inclusivity.

- *Role-playing* and simulations engage students in dilemmas like balancing renewable energy projects and community displacement, fostering empathy and collaboration. This approach complements the Design and Implement stages, integrating ethical trade-offs into system prototypes (Wibava et al., 2023).
- *Service-learning* blends academics with community engagement, such as designing affordable water filters for underserved areas. This method aligns with the Operate stage, connecting engineering expertise with sustainability and equity (Belefeldt et al., 2018).
- *Interdisciplinary workshops* bring diverse fields together, such as exploring autonomous vehicle ethics, enhancing holistic thinking during the Conceive and Design stages (Foski et al., 2017).
- Gamification introduces interactive tools, like VR simulations, enabling students to explore ethical trade-offs creatively (Sicart, 2015).
- *Research projects* with an ethical focus tackle issues like AI bias or environmental impacts, aligning with the Implement stage (Cacciattolo, 2015).
- Reflective journals span all CDIO stages, promoting continuous ethical learning and self-awareness (Swindell & Watson, 2006).
- *Faculty mentorship* guides students through ethical challenges, supporting all CDIO stages, while collaborative industry partnerships provide real-world experience in balancing economic and environmental priorities during the Implement and Operate stages (Oldenburg & Graves, 2024).
- *Scenario-based assessments* integrate ethics as a measurable outcome across all CDIO stages, ensuring accountability and critical thinking (Lohfeld et al., 2012)..

Collectively, these methodologies prepare engineers to address Industry 5.0's ethical complexities by balancing innovation with responsibility, contributing to sustainable and equitable solutions (Wibava et al., 2023).

Assessing ethical competence is a critical component of engineering education (Romero-Yesa et al., 2022), ensuring that students are prepared to navigate the moral and professional challenges they will encounter in their careers. In the era of Industry 5.0, where technology must align with human-centric and sustainable values, ethical competence assessment takes on an even greater significance. This process ensures that future engineers prioritize innovation that benefits society and the environment, fostering trust in engineering as a profession. To be effective, assessments must be holistic, combining theoretical knowledge, practical application, and reflective practices (see Figure 2). Embedding these assessment strategies into the CDIO framework ensures that ethics is integrated across all stages of the engineering process, enhancing both its relevance and impact (Martin et al., 2021).

Ethical competence assessment has three key objectives:

1. Moral reasoning – Evaluating students' ability to resolve ethical dilemmas in engineering contexts (Sancez et al., 2017).
2. Professional responsibility – Measuring understanding of codes of conduct, regulations, and societal impacts (Christie et al., 2003).
3. Reflective thinking – Encouraging self-awareness about the broader impact of engineering work (Lechasseur et al., 2018).

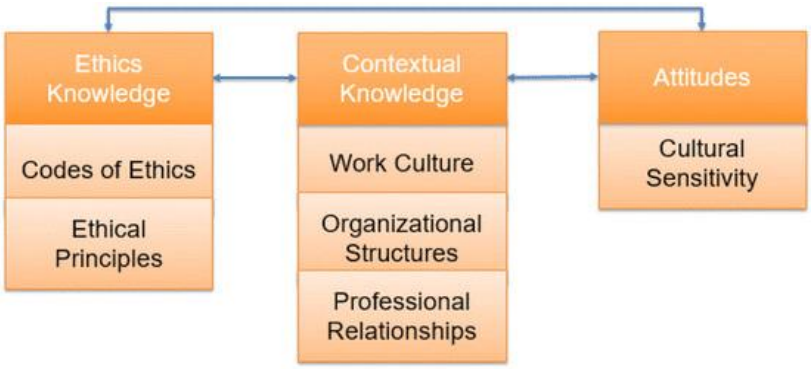


Figure 2. Theoretical framework for ethical competency assessment

These goals align with Industry 5.0's focus on sustainability, inclusivity, and ethical innovation, preparing students as responsible leaders. Methods for assessing ethical competence are:

- Scenario-Based Assessments: Engage students in dilemmas like AI in surveillance, fostering critical thinking during the CDIO's Conceive and Operate stages, addressing Industry 5.0 challenges (Ikonen & Kaasinen, 2008).
- Case Studies: Analyze real-world dilemmas like dam projects, integrating ethics into the Design and Implement stages (Al-Juboori & Noonan, 2024).
- Reflective Journals: Encourage introspection on ethical challenges, spanning all CDIO stages, enriched by peer feedback (Moloi, 2024).
- Group Discussions and Debates: Foster diverse perspectives on ethical issues like autonomous vehicles, enhancing collaborative skills in the Conceive and Design stages (Hanna et al., 2014).
- Role-Playing and Simulations: Provide practical experience in managing ethical dilemmas during the Implement and Operate stages, enhanced by VR (Schrier, 2017).
- Rubrics for Ethical Reasoning: Offer consistent evaluation across all CDIO stages, balancing qualitative and quantitative criteria (Tractenberg et al., 2016).
- Capstone Projects: Address comprehensive ethical challenges, embedding ethics across project development phases (Giacalone et al, 2003).
- Peer and Self-Assessment: Foster accountability and collaboration, applicable at all CDIO stages (Elliott & Higgins, 2005).

Challenges in assessing ethical competence include subjectivity, integration with technical assessments, and scalability for large cohorts. Solutions include co-designed rubrics, blended qualitative and quantitative methods, real-world contextual assessments, faculty training, and technology integration like AI and VR for scalability.

CASE STUDY: ETHICHS AND SUSTAINABILITY IN ENGINEERING EDUCATION AT AUSTRALIAN UNIVERSITY (AU)

Australian University (AU) has established itself as a pioneer in embedding ethics and sustainability into its engineering education programs. By aligning its initiatives with the CDIO framework and the principles of Industry 5.0, AU integrates ethics and sustainability across every phase of the engineering process, ensuring that students develop both technical and moral competence. Key Initiatives at AU include:

Ethics-Integrated Curriculum. AU's curriculum is designed to explicitly integrate ethical challenges, with a strong emphasis on sustainability and professional responsibility. Through

carefully structured coursework, students engage in critical discussions on ethical decision-making within the engineering profession. A key component of this approach is the course "Sustainable Engineering and Ethics," which delves into the ethical and environmental implications of engineering practices. Topics covered include energy production, waste management, urban development, and resource conservation, providing students with a holistic perspective on sustainability challenges. The course goes beyond theoretical discussions by incorporating real-world case studies, industry practices, and emerging global issues, allowing students to explore the ethical complexities engineers face in their professional roles. Through problem-based learning, ethical debates, and scenario analysis, students are encouraged to critically assess competing interests, consider long-term environmental and societal impacts, and formulate sustainable engineering solutions. By fostering an ethical mindset and equipping students with practical frameworks for ethical decision-making, AU ensures that graduates are prepared to uphold professional integrity while addressing the pressing challenges of modern engineering.

Real-World Capstone Projects. Capstone projects at AU provide students with hands-on experience in addressing real-world sustainability challenges. One notable project involved designing a solar-powered desalination system to supply clean water to rural communities in Kuwait. This initiative incorporated ethical considerations such as affordability, community involvement, and environmental sustainability. Students had to ensure the system was cost-effective and accessible, balancing economic feasibility with social responsibility. They also assessed the long-term environmental impact, reinforcing sustainable engineering practices. These multidisciplinary projects help students navigate complex ethical dilemmas in engineering. Through collaborative problem-solving, they gain practical exposure to real challenges. This fosters critical thinking and professional integrity. AU graduates emerge prepared to address societal issues with both technical expertise and ethical responsibility.

Industry Collaborations. AU's strategic partnerships with leading industries expose students to cutting-edge technologies and real-world ethical dilemmas. A collaboration with a renewable energy company, for instance, enabled students to design cost-effective solar panels tailored for Kuwait's climate conditions. These partnerships bridge the gap between academic learning and industry practices, equipping students with the skills to navigate ethical challenges in professional settings. Industry leaders have commended AU graduates for their ability to integrate sustainability and ethics into innovative solutions, reinforcing the university's reputation for producing industry-ready professionals. Furthermore, these collaborations provide students with internship opportunities and mentorship programs, enhancing their practical knowledge and ethical decision-making skills. As a result, AU graduates enter the workforce with a strong foundation in both technical expertise and responsible engineering practices.

Faculty-Led Ethical Mentorship. AU's faculty play a critical role in mentoring students on ethical challenges. Through programs like the "Engineering Leadership Program," faculty members provide personalized guidance on balancing innovation with ethical responsibility. Faculty development workshops equip educators with tools to integrate ethics and sustainability into their teaching, ensuring consistency and depth in mentorship. This initiative not only strengthens students' moral foundations but also prepares them for leadership roles in sustainable engineering, as reflected in the testimonials of graduates who credit faculty mentorship for shaping their professional ethics. Additionally, faculty members actively engage in industry collaborations and research projects, allowing students to explore real-world ethical dilemmas firsthand. By fostering a culture of ethical inquiry and critical thinking, AU ensures

that its graduates are well-equipped to make responsible engineering decisions in their careers.

Service-Learning Projects. AU emphasizes civic responsibility through service-learning projects that address sustainability challenges. For example, engineering students collaborated with local communities to improve water management systems in underserved regions, integrating ethical considerations such as equitable access and environmental preservation. These projects allow students to witness the societal impact of engineering firsthand, fostering empathy and a commitment to sustainability. One student remarked, "Working on this project taught me that engineering is not just about solving technical problems—it's about improving lives and protecting the environment."

While AU's initiatives have been successful, implementing them required overcoming several challenges:

- Balancing the Curriculum: Integrating ethics and sustainability into a technically rigorous curriculum necessitated significant redesign, requiring collaboration between faculty and curriculum developers.
- Resource Allocation: Securing adequate funding for sustainability-focused projects was challenging but addressed through strategic partnerships and grants.
- Cultural Sensitivity: Developing solutions that respect diverse perspectives required inclusive pedagogical approaches, such as incorporating region-specific case studies and engaging with local communities to ensure cultural relevance.

Identified challenges could be associated with the Four-Leaf Clover: A Conceptual Framework for Sustainability Education at Ohio State University shown in Figure 3 (Ohio State University, 2019). By utilizing this framework universities can facilitate collaboration between faculty and curriculum developers to balance technical rigor with ethical and sustainable considerations. Additionally, it can guide resource allocation by identifying key areas that require funding and support. Incorporating diverse perspectives within each area ensures cultural sensitivity, making the curriculum inclusive and relevant to various communities.

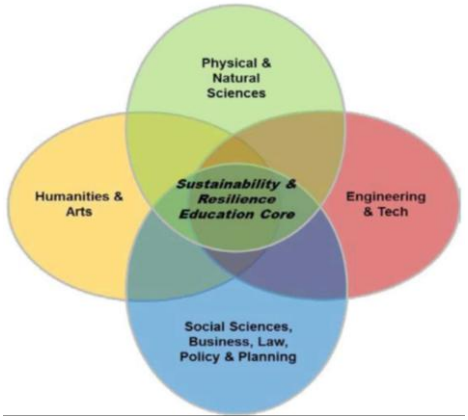


Figure 3. The Four-Leaf Clover: A Conceptual Framework for Sustainability Education at Ohio State University

AU's approach has yielded remarkable outcomes:

- Enhanced Ethical Awareness: Surveys reveal that 95% of AU engineering graduates feel confident in addressing ethical dilemmas in their professional roles.

- Sustainability-Driven Innovation: AU student projects have received national and international recognition for their focus on sustainability and innovation, including awards for renewable energy solutions and community-driven designs.
- Industry Readiness: AU graduates are highly sought after by industries prioritizing sustainability, with many securing positions in renewable energy, green technology, and socially responsible organizations.

The case study of Australian University (AU) highlights the transformative potential of integrating ethics and sustainability into engineering education. By embedding these principles into its curriculum, fostering interdisciplinary collaborations, and leveraging the CDIO framework, AU has created a robust educational model that prepares students for the challenges of Industry 5.0. Through innovative programs, real-world projects, and a commitment to cultural and professional relevance, AU equips its graduates with the technical expertise and ethical values essential for shaping a better world. This approach serves as a blueprint for other institutions, demonstrating that sustainable engineering is not just a technical pursuit but a moral imperative for addressing global challenges (Giacalone et al, 2003).

CONCLUSION

The integration of ethics and professional responsibility in engineering education is no longer optional but a vital necessity in preparing future engineers to address the multifaceted challenges of Industry 5.0. This paper has explored the essential dimensions of embedding ethical competence into engineering education, aligning with the CDIO framework to ensure that ethics permeate every stage of the engineering process. Through methodologies such as scenario-based assessments, reflective journals, and interdisciplinary projects, institutions can effectively instill ethical reasoning and professional responsibility in students (Martin et al., 2021). The implications of this approach extend beyond individual competence. By fostering ethical decision-making and a commitment to sustainability, engineering education contributes to societal well-being, environmental preservation, and economic resilience. Institutions like Australian University (AU) demonstrate how integrating ethics and sustainability into curricula prepares graduates to lead in a rapidly evolving global landscape (Martin et al., 2021). Looking ahead, the future of engineering education lies in leveraging immersive technologies, gamification, AI-driven tools, and interdisciplinary collaboration to enhance ethical awareness and sustainability practices. These innovations ensure that engineering education remains dynamic and responsive to global challenges, fostering a new generation of engineers who are not only skilled innovators but also ethical leaders (Abuliobdeh et al., 2024). In conclusion, the journey toward ethical and sustainable engineering education requires a collective effort from universities, industries, and policymakers. By prioritizing ethics and sustainability, we can ensure that engineering graduates are equipped to build a future that is not only technologically advanced but also equitable, sustainable, and human-centric—hallmarks of Industry 5.0. This commitment to ethical competence will shape not only the engineers of tomorrow but also the world they help create (Lechasseur et al., 2018).

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A FRAMEWORK FOR THE TEACHING OF AUTONOMOUS MOBILE ROBOTICS

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ABSTRACT

A framework for teaching Autonomous Mobile Robotics is presented. The activity is part of the Bachelor's program in Artificial Intelligence at the Federal University of Goiás, Brazil. The program runs over four years, and the framework was built as a design-implement experience for a course module in autonomous mobile robotics in the fourth year. The first years of the program contain mandatory course modules in entrepreneurship, mathematics, and computer science, and the course module in robotics is the second one where students are introduced to a design-implement experience based on the CDIO framework. The course module was designed in collaboration with engineers from Synkar Autonomous in Brazil to validate the design process. The course framework consisted of software and hardware resources, such as container virtualization to run repeatable test cases, ROS2 for developing robotic software and applications, project management using kanban to suit the lifecycle of robotic prototyping (i.e., hardware-based software development), and the "Albot" customized robot designed for the practical experiences. As a result, we created a first design-implement experience in robotics, that was able to match basic professional skills demanded by industry, such as agile development, reproducibility, and software modularization. The framework also served to train the students with the best practices and modern methodologies used by leading companies in robotics. Finally, some reflections and lessons learned were pointed out to further improve the course module in future.

KEYWORDS

Design-implement experience, robotics, project-based learning, Standards: 2, 4, 5, 11.

INTRODUCTION

A key aspect of the CDIO framework is closing the gap between higher education programs and professional work in terms of the competences and skills required of graduates (CDIO Initiative, 2025). With the rapid growth of robotics and artificial intelligence applications, the use of standardized software development tools and agile methods for project management became crucial for companies to deliver scalable robotic products and services. The key to this is to work on standardized methods and professional practices. The present is a follow-up on prior work of the authors, where they introduced a first CDIO design-implement experience at the Computer Vision course module of the Bachelor's in Artificial Intelligence program, at the Federal University of Goiás in Brazil (Gunnarsson & Díaz-Salazar, 2023).

Although design-implement experiences represent a vital component of the CDIO framework (see Standard 5), there is a lack of approaches designed in actual collaboration with the industry. Numerous examples of design-implement experiences have been presented within the CDIO community, and many of them can be accessed through the CDIO website (CDIO Initiative, 2025). For instance, a successful example was presented in (Svensson & Gunnarsson, 2012). For the specific topic presented herein, *i.e.* design-implement experiences within robotics, artificial intelligence, and software development carried out in close collaboration with start-up companies, it is difficult to find examples of design-implement experiences connected to the CDIO framework. Hence the paper has potential to be a contribution to the CDIO community.

BACKGROUND INFORMATION

The CDIO framework

While the idea of sharing our world with robots that cooperate smoothly with us humans is exciting, training undergraduate students with the competences required by the robotics industry is more than challenging. For instance, one of the major issues relies on the high costs of implementing a robotics laboratory and training people for teaching, which means having access to open-source hardware and resources that, more than often, are not publicly available. Today, the integration of a professional robotics curriculum into an educational setting demands access to proprietary tools, and without the direct support of industry in the integration process, it will remain prohibitive for most institutions. In addition to this, bridging the gap between theory and practice is always a challenge for educators: How to teach robotics effectively? How to set up a working framework for robot operation? How to evaluation the learning outcomes during examinations?

In an approach to address part of the challenges, in this work we proposed a first design-implement experience in robotics based on the CDIO framework. The key to success in this case was the establishment of a strategical partnership with the Synkar Autonomous company (Synkar Autonomous, 2024), to explicitly involve them during the design process, lectures and evaluation of the course module. Synkar is a robotics company working with autonomous last-mile delivery of products and services in Brazil and abroad. The partnership with Synkar allowed us to propose a design-implement framework for the teaching of robotics with a strong focus on best practices and skills required from professionals in robotics. We believe that such methodology will allow us to succeed in delivering graduates to society, who are not only technically competent, but also possess experience in problem-solving and communication, as described in (Mezilov *et al*., 2024).

The CDIO framework in Brazil

The CDIO framework is receiving considerable attention in Brazil, starting with the adoption by the Military Engineering Institute (IME). Several universities have joined the CDIO Initiative with increasing contributions to the CDIO literature describing the implementation of the CDIO framework in the Brazilian context. Examples of the latter are (Lourenco & Veraldo, 2015), (Neto *et al.,* 2019), (Passos *et al*., 2019), and (Rezende *et al.,* 2022). Moreover, CDIO can be instrumental towards implementing the Brazilian national guidelines for engineering education, as pointed out in (Rezende *et al.,* 2022). However, stronger connections of the CDIO International community with the Latin American region can be further improved by promoting interactions during the regional meetup events, as observed at the CDIO Conference in Trondheim 2023, where a lack of participants was noticed during the Latin American meetup.

THE CONTEXT OF THE DESIGN-IMPLEMENT EXPERIENCE

The Federal University of Goiás

The Federal University of Goiás (UFG) is the largest public university in the Central-West region of Brazil and is in the city of Goiânia. In numbers, the university has 60 years of history, with 104 undergraduate schools, 78 post-graduate programs, and approximately 22,000 students distributed across four campuses. The module in Autonomous Mobile Robotics is taught in the fourth year of the program in Artificial Intelligence, which is run by the Institute of Informatics.

The Bachelor's Program in Artificial Intelligence

The Bachelor's program in Artificial Intelligence (BIA) at UFG is the first undergraduate program in Artificial Intelligence launched in Brazil and started the activities in March 2020. The entrance examination is run yearly through a nation-wide evaluation, with 30 new students entering the program in every class. The first class concluded activities in February of 2024 and, by January of 2025, there are five classes running courses simultaneously.

The BIA is a four-year program composed of eight semesters corresponding to 3,200 hours. The first three years include course modules in Entrepreneurship, Mathematics, Computer Science, Machine Learning, and Deep Learning. The module in Autonomous Mobile Robotics runs in the seventh semester, with 96 hours of credits in total, and it is the second course module where students are introduced to a design-implement experience according to the CDIO framework, the first course being Computer Vision taught at the fifth semester. The fourth year includes course modules on specialized topics, such as Natural Language Processing, Reinforcement Learning, Robotics and Big Data. The program concludes with the Residence in Artificial Intelligence, which is a course module of 320 hours where students elaborate a capstone project and present it publicly, as part of the requirements for graduation.

A FRAMEWORK FOR TEACHING ROBOTICS

The main contribution of this work to the CDIO community is the proposal of a framework for the teaching of robotics that was defined in close collaboration with an industrial partner (Synkar Autonomous) to train practitioners with modern hardware and software tools that are used in actual professional robotic products and services. The partnership with Synkar has a successful history of recent cooperations, since they are a former spinoff of the local hub of entrepreneurship at the Federal University of Goias and received financial support from the

research group on five projects already through the EMBRAII program of innovation (a governmental initiative in Brazil). More specifically, the authors worked together with engineers from Synkar in tasks such as the choice of lecture topics to be discussed, the design of practical laboratories and the proposal of benchmarks for evaluations.

In sum, the proposed framework includes tools such as Docker, ROS2, and Agile development, which are all part of the regular workflow of world-class companies in robotics, such as Tesla, Boston Dynamics, and Synkar on itself. These tools allow companies to deploy products and services that have reproducible results and that can be verified and tested in controlled environments of operation. The educational framework proposed in this work incorporates adapted versions of such tools to cope with specific robotic equipment of the course module. For instance, we adopt Turtlebot as the main platform for teaching, but we also have projects using quadrotors and quadrupeds.

Docker

Docker is a virtualization tool that allows us to develop fully functional work environments in software development (Docker, 2025). Docker is extensively used in modern robotics development due to the use of containers, which are software-defined machines that encapsulate the specifications of a particular software stack, allowing for a controlled operation of the robot's software and the interaction with its low-level hardware interfaces and sensors. The containers enable development of modules of individual features and functionalities of a robot, making it easy to test and debug before going to production. Particularly, we adopted Docker as a strategy to bring the educational context of learning robotics closer to the skills demanded in professional software and hardware services.

ROS2

ROS2 is an open-source robotic framework for the development of applications and services. ROS2 facilitates the design of robotic hardware and software and its simulation in realistic scenarios of operation. Compared to the first version, the architecture of ROS2 is based on the concepts of nodes and topics that make the integration of hardware and software easier and that also facilitates operating robots in swarms of networked environments for Industry 4.0 applications. In this work, we adopted ROS2 for the practical laboratories, giving special attention to the creation of ROS packages, which are customized software modules developed by the students to achieve specific robot tasks. Examples of such tasks are teleoperation and robot localization by fusion of lidar and wheel encoders. The ROS2 setup used in our framework also included the CAD model of a differential robot called "Albot", that was designed for the course module and that can operate in different virtual work environments. From the educational perspective, ROS2 has the additional benefits of being industrial-grade and well documented (Bonci *et al*., 2023).

Agile development

We adopted the agile methodology for the execution of the course module's laboratories. The laboratories consisted of developing software modules that incrementally enabled features of the robot, such as teleoperation or localization. The deliveries were submitted using GitHub Classroom repositories, to control the software versioning and documentation. On a typical repository workspace, the students received basic software templates to startup and a kanban board for monitoring the activities of their projects. The kanban board allowed them to map the lifecycle of a project using a simple strategy based on three stages: "to do", "doing", and "done". The students were evaluated according to the completion of the tasks allocated on

each of the stages. The kanban model also allowed them to measure the time execution of the tasks. When performing work in groups, the student's teamwork was supervised through the assignment of the tasks to the individuals of a group and making it easier to follow-up. Agile development is the current standard for project management in modern IT companies and was also adopted in the robotics industry due to its effectiveness (Cao *et al*., 2009).

Albot

Albot is a differential-drive robot designed for the course module in collaboration with (Pequi Mecanico, 2025) and was designed to serve as a platform for the laboratories. Albot is a two-wheel drive robot with a castor wheel and a size of 544x455x413 millimeters. The robot hardware consists of sensors, such as 2D lidar, IMU with 3-axis accelerometers, gyroscopes and magnetometers, wheel encoders, and a camera. Figure 1 shows the schematic of the robot and its operation in a simulated warehouse environment using a vision sensor. The robot model was released under the open-source license and the source code for the simulation can be found on (Albot, 2025).

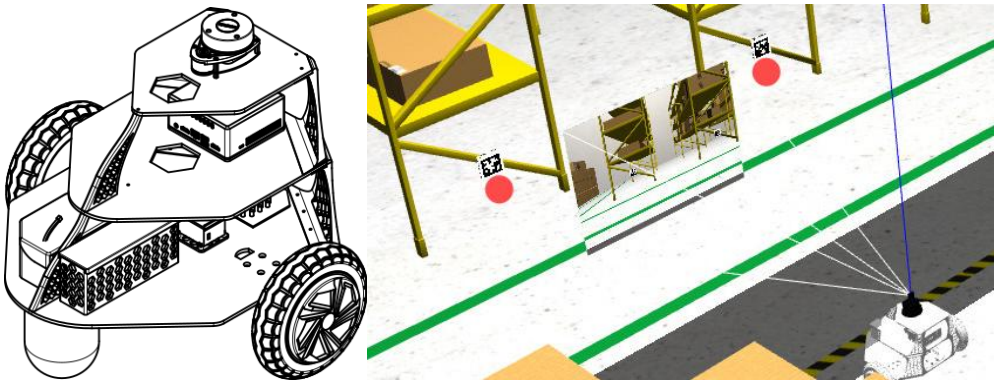


Figure 1. Left: The robot Albot. Right: Simulation of Albot in a warehouse performing localization with known correspondences using AprilTag fiducial markers. A visualization of the forward-looking camera is displayed and highlighted in white rays.

Structure of the course module and learning goals

The course module in Autonomous Mobile Robotics runs over 16 weeks and corresponds to approximately 4 ECTS credits (60 ECTS credits correspond to one year of full-time studies), which means the students are expected to spend 96 hours on the module.

The learning outcomes contain goals related to:

- (Unsupervised) Explain the basic concepts involved in robotic perception and action.
- (Supervised) Apply computer vision techniques to robotic solutions.
- (Following instructions) Apply localization and mapping techniques.
- (Following instructions) Design robot perception and action solutions.

The text in parentheses refers to the levels of incremental learning outcomes of a student towards reaching a goal and they are specified in the Study Plan document of the bachelor's program. These levels serve as checkpoints for the instructor to measure the learning process throughout the course progress. For instance, in the "Unsupervised" level, the students are expected to reach a goal independently without the support from the instructor. On the

contrary, at the “Supervised” level, the instructor acts as a guide to help students to reach a goal in a less independent approach. In the “Following instructions” level, the students are expected to execute procedures and methods adequately as specified by the instructor.

Work process and assessment

Twenty-two students attended the lectures and laboratories. When running practical activities, the class was divided into five teams, with an average of five students per team. The teams were sorted out by the students, and each team was required to have a leader who handled the team’s management and communication with the instructor.

Four laboratories of three-weeks in duration were performed. They involved the topics of teleoperation, Kalman filtering (KF), Extended Kalman filtering (EKF) and Simultaneous Localization and Mapping (SLAM). The deliveries were performed via incremental submissions through repositories for version control and documentation. As stated by the students, the course in Autonomous Mobile Robotics is both theoretically and practically demanding. Thus, the laboratories were fundamental to drive the learning process of assimilating complex theoretical aspects into actual robotic applications. The challenge was always to motivate the students towards gaining confidence with the implementation of difficult tasks such as robot localization and mapping.

Three evaluations were applied to the students, covering topics such as kinematic modeling of the robot, robot localization with KF and EKF, and SLAM using a combination of lidar and wheel encoders. Each evaluation consisted of a practical challenge designed as a problem-solving scheme that addressed a specific robot task, for instance, controlling the robot with operation from a distance, or mapping and recovering the robot position within an environment that was completely new to it. The assessment was performed in terms of the level of completion of the tasks and some algorithm-specific metrics, such as the total error in odometry or the stability of a localization filter over time. Additional evaluation criteria were focused on the students’ design process in terms of prototyping and building the required software packages. The final grade was complemented by an examination that included a written technical report and an oral presentation.

Examples of project tasks and results

The students were introduced to the fundamentals of probabilistic robotics during the lectures, which is the basis of autonomous robot tasks, such as locomotion, kinematics, perception, and localization. Learning robotics in a probabilistic manner enables students to deal with robotic algorithms that can handle uncertain and dynamic scenarios typical of real-world problems, as required in professional services. At the center of probabilistic robotics is the idea of estimating the position and orientation of a robot from sensor data, which in turn deals with the problem of estimating quantities that are not observable directly, but that can be inferred, such as determining the localization of a robot from the set of images of a camera in combination with odometrical data from wheel encoders.

The laboratory sessions focused on solving the previous theoretical problems through the implementation of algorithms in practice. One of the first methods in autonomous robotics is the Kalman filter because it is at the core of many localization problems and, and it provides a convenient setup for discussing some of the key aspects that occur in practice. For instance, the students had the opportunity to experience how to deal with the uncertainty present in the actuators and sensor data by implementing a Kalman filter and were also introduced to the vocabulary and terminology used in modern robotic projects. At the end, three evaluations

were applied covering the aspects of kinematic modeling, robot localization and SLAM, as detailed below.

Assessment 1: Kalman filter with constant velocity model

In the first assessment, the participants had to implement a Kalman filter to determine the localization of a vehicle driving through a tunnel without the support from GNSS signals. The only data provided was the velocity in the driving direction from which the students were required to infer the position of the vehicle. Additionally, they had to perform a statistical analysis of the system by corrupting the input data and tuning the covariance matrix of the Kalman filter to keep the filter stability. The experience was implemented with focus on the "Following instructions" learning goal, which means that the instructor provided a template code with guidelines and steps to help the students to develop and customize a first localization filter.

Assessment 2: Extended Kalman filter localization

In the second evaluation, the students implemented a more advanced localization algorithm using the extended Kalman filter. The scenario was a robot moving with constant turn rate in a circular trajectory. In this case, the input data included the velocity of the vehicle, its 2D position and orientation and the goal was to localize the robot on a map. The students were instructed to perform statistical analysis of the data and the system, as in the first assessment, but taking acquaintance of new problems such as the non-linearities present in the design of the filter models. The learning outcome covered in this case was the "Supervised" level, in which the students proposed solutions that were discussed and validated with the instructor.

Assessment 3: EKF-SLAM with known correspondences

The third assessment aimed to evaluate competences in simultaneous localization and mapping (SLAM), which is a fundamental problem in autonomous navigation and mobile robotics. In this case, the students were required to calculate the position of a robot and, at the same time, generate a map of the environment with the coordinates of visual markers encountered along the robot path. This is a problem that is common in scenarios where a robot moves in an environment that is totally new and without previous knowledge of it, such as in robot exploration, search and rescue missions, or last-mile delivery of products, as performed by Synkar. The students already had a solid basis for building own solutions at this stage of the course module, so the "Unsupervised" learning goal was committed in this case.

Observations and student feedback

Some observations and lessons learned can be summarized by the end of the learning activity:

- We used state-of-the-art hardware and software resources used by industry, but those are computationally demanding and, due to this, they could not run efficiently on the computers we had at the local facility. For instance, we needed to swap the ROS2 simulation of the TurtleBot4 robot platform, that was intended to be used originally, with the simulation of the Albot robot because it was a much lighter model to use. This change caused a delay during the preparation of the course activities, which needed to be reformulated to meet the expected duration.
- A second thought is related to the time required to build a first functional framework. This was a hard challenge due to the limited infrastructure we received, which made it difficult to prepare the coursework. Most of the course preparation hours were allocated into

building a working container image, integrating the framework parts (Docker, ROS2, Agile), and designing the Albot robot.

- A third consideration is that the students receive additional follow-up supervision from the teaching assistant weekly. This was an important service that was made available for extra class support and that helped students to reach the learning goals, especially during the execution of practical experiences.

At the completion of the course module, twenty-one students passed (95%), with only one student failing (5%) due to absence during the evaluation process. In general, the overall feedback from the participants concerning the design-implement experience was positive. As feedback for future, the students suggested incorporating more challenges into the framework involving machine learning and artificial intelligence methods, as revealed by the class survey results in Table 1. See (SIGAA, 2023).

Table 1. Results of the teaching evaluation by the class

N	Suspensions	Dimension 2		Dimension 3		Total Avg. [1]	Total Std. [1]
		Avg.	Std.	Avg.	Std.		
22	0	6.35	3.78	9.77	0.60	6.35	3.51

[1] Total Average and Total Standard Deviation are calculated from Dimension 1 -“Institution by the Student” and Dimension 2 - “Instructor by the Student”, which are metrics calculated from an institutional survey that UFG applies to the students at the end of each semester, with a maximum of 10.00 points. Dimension 3 is another metric, entitled “Self-assessment by the student”, which is also calculated from the same survey.

CONCLUSIONS

In this work we described a framework for the teaching of Autonomous Mobile Robotics that has, as a main contribution, the collaboration of a key industrial partner in robotics. The course module was structured as a design-implement experience in the Bachelor’s program in Artificial Intelligence at the Federal University of Goiás in Brazil. We made use of professional tools, such as Docker, ROS2, and Agile methodology that were customized in cooperation with the Synkar company to strengthen the skills and knowledge required in professional robotic products and services. Moreover, the course was designed on top of three learning goals covering unsupervised, supervised and following instructions levels of accomplishment. A first take-home message to the CDIO community is to incorporate local industries in the design-implement processes. The students appreciated the proposed framework from a professional and technical perspective. As shown by the results, the course helped them to incorporate basic professional skills required to develop robotic applications in industry and to put project management abilities in practice. A second contribution to the CDIO community would be to use open-source resources for teaching as much as possible. In case of financial restrictions, the use of customized robot simulation in ROS was key. Finally, the main concern of the class was not related to the proposed framework itself, but to a special request, in which they were asked to incorporate more practical activities involving machine learning methods.

In future, we can also incorporate more individual evaluation methods, such as interviews to have student feedback with finer granularity.

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GREEN GROWTH AND CDIO APPROACH IN FOOD ENGINEERING: INITIATIVE AND IMPLEMENTATION MODEL

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ABSTRACT

Currently, the idea of "green growth" represents the modern paradigm for climate change mitigation that economists and policymaker's support. The need to lower greenhouse gas emissions linked to economic growth necessitates the development and application of sensible policies. Despite differences in viewpoints regarding the risks and difficulties involved, green growth is still a seemingly unstoppable option to meet the demands of climate change and guarantee the sustainability of human existence. In this context, it makes sense in this situation to incorporate green growth concepts into engineering education. Including instructional modules that highlight sustainable practices is crucial given the widespread impact of technological practices on the economic and environmental landscapes. Future food engineers must be prepared to handle the difficulties posed by the impact of the food industry, as food engineering is crucial to human development. By that way, future professionals can effectively contribute to the demands of sustainable development by fostering an awareness of green growth in engineering education, which strengthens the mutually beneficial relationship between environmental responsibility and technological advancement. Using the CDIO approach to combine green growth into food technology training programs will help guarantee that this content is efficiently developed and turns into a beneficial skill that complement the development of future engineers as well as food technology. In order to effectively develop future food engineers' skills in line with the demands of the modern era, this article offers a model that incorporates green growth content into university not only food technology (FT) programs but also Engineering/Technology (ET) programs using the CDIO approach.

KEYWORDS

Green Growth Indicators, Sustainable Development, CDIO Framework, Engineering Education, Curriculum Integration, Standards: 1, 3, 4, 5, 7, and 8.

NOMENCLATURE

OECD	Organization for Economic Co-operation and Development
GG	Green Growth
CDIO@FT program	CDIO integrated Food Technology
CDIO@ET program	CDIO integrated Engineering/Technology
GGI	Green Growth Indicator
EEPs	Energy-Efficient Products
GCE	Green and Circular Economy
R&D	Research and Development

INTRODUCTION

The significance of sustainable development has gained widespread recognition in recent decades due to significant negative effects of global environmental changes. Numerous conservation activities and industry-wide laws are being improved to control human negative impacts on nature. There are many technological alternatives whose development is encouraged to bring cost-effective, environmentally friendly technologies into human life. Future engineers must have sufficient knowledge and skills to control the negative impact of production and consumption on the environment, which must fundamentally be carbon neutral. This is not only a requirement of this time, but also the responsibility of engineers, since they are the main actors in the conception, design, development, manufacture and operation of products in practice, with the aim of reducing the negative impact of production systems on the environment. In this context, the CDIO curriculum has been further developed with content on sustainable development and places a greater emphasis on environmental issues. Based on these sustainability aspects, the CDIO curriculum with several environment topics has been integrated into version 2.0, including sections 4, 4.1, 4.1.7, 4.4.6, 4.5.1 and 4.6.1.[1] The update of curriculum from the prevailing version 2.0 to a new version 3.0 was motivated by the emergence of external change drivers and internal experiences within the CDIO community.[2] CDIO syllabus, in both versions 2.0 and 3.0, has incorporated elements of sustainable development, recognizing its growing importance in engineering education. There, sustainability is one of four themes that categorized in the curriculum. It can be concluded that the current version of the CDIO curriculum is partly based on sustainability competencies to ensure the development of engineers in the time of adaptation (Table 2).

Green Growth (GG), one of the concepts, is also a vision or an economic development approach that also includes and takes into account aspects of the living environment. This term is also applied to the sustainable development approach that the world is pursuing today to address the crisis of our time: Climate change.[3] Green growth includes Growth (Economic sustainability), Clean (Environmental sustainability) and Resilience (Social sustainability). These three poles are about optimizing the use of natural resources, minimizing pollution and environmental impacts, as well as managing natural hazards and the role of governance environmental and natural resource management in preventing natural disasters. Green growth is economic development that must be low-carbon and resource-efficient, socially inclusive and adaptable, create new jobs, often include innovative approaches and new technologies, while protecting environmental biodiversity and ecosystems. Innovation is the linchpin when managing the delicate balance between growth and environmental sustainability while aligning with social sustainability. Pushing the frontier outward through innovation is not merely about finding more efficient ways to use natural resources, but also about fostering a mindset of continuous improvement and creative adaptation. Innovation not only helps decouple growth from natural capital depletion but also catalyzes a ripple effect:

spawning new ideas, entrepreneurs, and business models. Not only does this contribute to economic growth, but it also emphasizes the symbiotic relationship between green practices and overall prosperity. As playing a key role in the development and implementation of new products that serve human life, engineers must not only have strong skills to adapt in the new context of the economy but also have practical experience to acquire creative thinking skills integrated green growth requirements.

With the aim of collecting the specified index for analysis and monitoring the progress of the transition to green growth, the OECD has established a small set of measures.[4] In the framework of measurement, a logical starting point for identifying Indicators of Green Growth (GGIs) for goods or services is the area of production where growth directly contributes to economic expansion, utilizing natural resources as inputs and releasing pollutants and residues into the environment. The indicators include monitoring environmental and resource productivity, monitoring the natural asset base, monitoring the environmental quality of life, and monitoring economic opportunities and policy responses. To integrate sustainable development principles into CDIO, GGIs can be used as a framework that adapts the curriculum to the needs of new global situations. The indicators can also be used as a benchmark and motivation for development of products that contribute to sustainable development. Integrating green growth indicators into every phase of product development according to the CDIO curriculum not only creates an innovative framework aligned with current trends, but also ensures that green skills become an important part of the skills of future engineers.

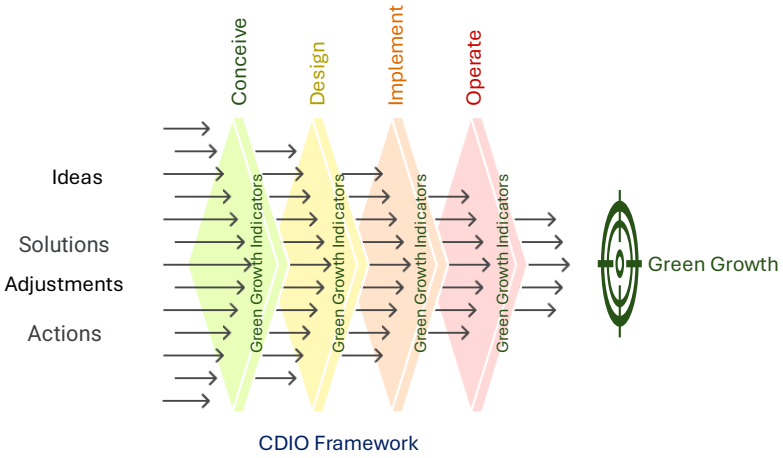


Figure 4. Application of Green Growth Indicators in the CDIO Framework

The pressing need for sustainable practices and the rising demand for safe, high-quality food products are driving a significant transformation in the modern food industry. To address these issues, Duy Tan University's Food Technology (FT) program has painstakingly developed a thorough curriculum that not only provides a solid grounding in the scientific principles of food technology but also cultivates the hands-on abilities and creative thinking required for success in this fast-paced industry. The curriculum is carefully crafted to produce future food engineers who are not only technically skilled but also capable of spearheading innovation and leadership in the sector. Conceiving, Designing, Implementing, and Operating (CDIO) principles are seamlessly incorporated into the curriculum's core, guaranteeing that students obtain practical experience and cultivate a thorough understanding of the full product development lifecycle. Furthermore, the program actively integrates Green Growth Indicators (GGIs) into its curriculum in recognition of the critical role sustainability plays in the

contemporary food industry. By using these indicators as a framework, the curriculum is modified to meet the needs of a world that is changing quickly and to guarantee that our graduates are equipped to help create a more sustainable future.

Table 2. Examples of CDIO and green applications in projects

Project Area	**CDIO Stage Focus**	**Green Growth Principle Addressed**	**Reference**
Clean Technology Integration in Engineering	Design, Implement	Innovation, Reduced Pollution	[5]
Petroleum Engineering Curriculum Reform	Conceive, Implement, Operate	Environmental Responsibility, Carbon Footprint Reduction	[6]
Solar-powered Water Purification System	Implement, Design	Resource Efficiency and Environmental Sustainability	[7]
Sustainable Urban Drainage Systems	Implementation	Resource Efficiency and Environmental Sustainability Within Urban Infrastructure	[8]
Sustainable Wastewater Treatment System	Design, Implement	Environmental Sustainability, Low-energy, Ecological Balance, Resource Efficiency	[9]
Sustainable Design and Build Project	Design, Implement, and Operate	Sustainable Development, Environmental Stewardship, Environmentally Friendly Materials, Energy Efficiency, Waste Reduction, Sustainable Infrastructure	[10]

This article introduces the set of indicators based on green growth principles suitable for application and integration into not only Food Technology programs but also other CDIO integrated Engineering/Technology (CDIO@ET) curriculums.

INDICATORS SET FOR CDIO@ET CURRICULUMS

By the original purpose, the GGIs developed by the OECD serve as a flexible framework for measuring and monitoring progress towards green growth across various aspects of society. This framework is intended for a wide range of stakeholders, including nations, industries, organizations, and individuals. Moreover, the GGIs also offer an approach to assessing and fostering green growth.

By integrating GGIs into the CDIO@ET curriculums and syllabus, educators ensure that engineering students understand the importance of sustainability in their field. On the other hand, CDIO focuses on connecting engineering education with real-world applications. By incorporating GGIs, students can apply their technical skills in projects and designs that are aligned with sustainable development goals. Additionally, sustainability and environmental responsibility are among the most important ethical considerations in modern engineering

practice. GGIs provide a structured opportunity to teach students these ethical principles and prepare them for responsible engineering careers. As many industries shift to sustainable practices, CDIO@ET programs with GGIs equips students with the skills and mindset required in industries that increasingly emphasize green growth and environmental awareness.

Incorporating sustainable design principles into each phase of CDIO can contribute to GG by ensuring that engineering projects align with the green growth strategy. Furthermore, implementing engineering solutions consistent with sustainable practices can contribute to GGIs by emphasizing the long-term sustainability of engineering, taking into account sustainable development factors. Additionally, in addressing complex environmental challenges that often require solutions that span multiple engineering disciplines, CDIO will encourage interdisciplinary collaboration, and bring together different fields of engineering where GG become more of a reality. This makes CDIO's project-based learning approach a good fit not only with GG, but also with a deeper understanding of green growth principles. Furthermore, CDIO encourages innovation, creativity and problem-solving scenarios in technical solutions. This can contribute to GG by encouraging the development of innovative, environmentally friendly technologies and practices and addressing real-world issues related to sustainable development.

Essentially, GGIs integrated CDIO@ET curriculums provide a framework for training engineers guided by the principles of green growth and sustainability. CDIO, which focuses on conception, design, implementation and operation, can contribute to several key elements of green growth through a set of indicators that are selected and flexibly changed according to the processes in each phase of the engineering project. This approach allows educators to design curricula to address not only technical issues but also environmental concerns. This ensures that engineering students graduate with a comprehensive understanding of how their work can positively impact the environment and contribute to sustainable development.

Environmental and resource performance indicators

Box 1. Key indicators for productivity categories

Labor Productivity
- Output per hour worked
- Output per employee
- Value added per worker

Environmental Productivity
- Carbon intensity
- Water use efficiency
- Energy efficiency

Resource Productivity
- Material efficiency
- Land resource efficiency
- Water resource efficiency

GGIs must accurately identify key environmental services and seek to quantify, where possible, their impact on economic growth. In the indicators set of environmental and resource productivity, the measures can be divided into labor productivity, environmental and resource productivity.

The natural asset base

GGIs not only focuses on traditional measures of output and income growth but must also consider the preservation and sustainability of critical assets. These assets include both produced assets and, crucially, natural assets and environmental resources. The measurement includes carbon balance as well as natural quality and health.

Box 2. Key indicators for the natural asset base

Carbon-related rates

- Carbon emissions
- Carbon sequestration

Natural quality and health

- Availability and quality of freshwater resources
- Soil quality and health
- Biodiversity
- Forest cover, deforestation rates
- Health of marine ecosystems

Indicators of the environmental quality of life

In addition to the consideration of keeping society's asset base intact, GGIs must also reflect the quality of life and the direct impact of the environment on people's quality of life. Environmental quality of life indicators includes environmental quality, environmental risks and basic environmental services.

Box 3. Key indicators for the environmental quality of life

Environmental quality

- Air quality
- Water Quality
- Health-Related Indicators

Environmental risks

- Industrial pollution
- Hazardous waste
- Pollution intensity
- Natural disasters

Basic environmental services

- Clean water and treatment
- Sanitation and sewage treatment

Indicators of economic opportunities and policy responses

GGIs must reflect the potential for green growth and the effectiveness of policies to promote environmentally sustainable economic development. Collectively, these indicators provide insights into the economic opportunities and policy responses related to the transition to green growth and provide a comprehensive overview of efforts to balance economic development with environmental sustainability.

Box 4. Key indicators for economic opportunities and policy responses

Green and Circular economy

- Renewable energy generation
- Energy efficiency

- Green jobs
- R&D focusing on green technologies and sustainable practices
- SDGs Achieving
- Environmentally sustainable projects and businesses
- Percentage of waste recycled and diverted
- Product life cycle and recycling efficiency
- Adoption of carbon pricing mechanisms

Social and Inclusive Growth

- Reduce poverty rates and income inequality
- Education and training for sustainable development

Environmental Performance

- Emissions reduction targets
- Air and water quality reflection

Resilience and Adaptation

- Country's or region's resilience to climate-related risks
- Preparedness and response capabilities for natural disasters

Consumer and Corporate Behavior

- Consumer behavior promoting sustainable and eco-friendly products
- Businesses' environmental and social performance

CDIO@FT PROGRAM AT DUY TAN UNIVERSITY

Duy Tan University's 4.5-year Food Technology program (151 credit hours) provides comprehensive food technology education, integrating lectures, labs, e-learning, communication, ethics, and critical thinking. Hands-on learning is emphasized through CDIO projects, real-world applications, and a graduation internship.

Food Technology program, built on the CDIO framework, features a core structure of four courses designed to progressively develop students' skills in conceiving, designing, implementing, and operating innovative solutions within the food industry. These courses—FSE 296, FSE 396, FSE 496, and FSE 447—guide students through increasingly complex projects, culminating in a capstone graduation project.

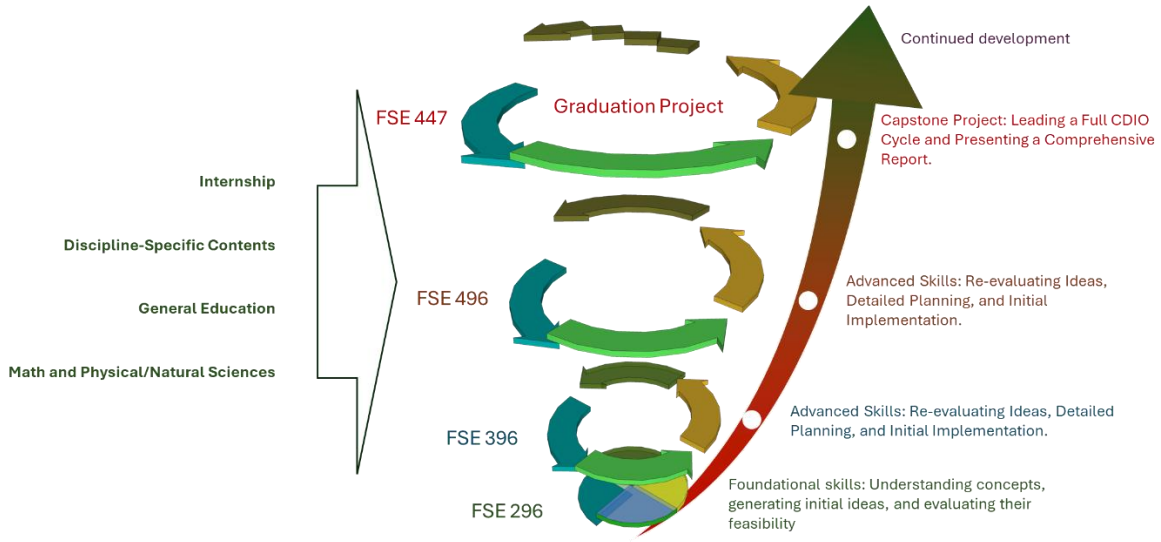


Figure 5. CDIO@FT Program at Duy Tan University

With an emphasis on the project lifecycle and conceiving/designing solutions, students in FSE 296 acquire the fundamentals of CDIO, generate preliminary concepts, and assess viability. Building on this, FSE 396 requires students to reorganize groups, polish concepts, and prepare for execution, including preliminary testing. With a focus on assessing practical value through the application of scientific methods in food technology, FSE 496 leads students through the entire CDIO cycle, which includes reevaluating concepts, restructuring, and executing conceive, design, implement, and operate.

In this capstone project (FSE 447), each student leads a team of second and third-year students, mentoring them through a complete CDIO cycle. Teams re-conceive and implement innovative ideas, producing a comprehensive graduation project report. This report is presented to a faculty scientific committee for evaluation, showcasing students' comprehensive understanding and application of CDIO principles.

INTEGRATION GREEN GROWTH INDICATORS INTO CDIO@FT CURRICULUM

Integrating GGIs into the CDIO@FT curriculum can be a mutually beneficial process, with both GGIs and CDIO contributing to each other. Linking the goals and methodologies of GGIs and CDIO, educators can create a comprehensive learning experience that provides students with the knowledge, skills, and motivation to contribute to green growth and sustainable development in their engineering practices.

Integrate Green Growth into the Conceive phase

Food technology faces the complex task of providing safe, nutritious, and appealing food for a growing population while minimizing its environmental impact. While addressing fundamental challenges like food security and nutrition remain paramount, integrating Green Growth Indicators (GGIs) into the Conceive phase can ensure that sustainability is considered alongside other critical factors.

GGIs can promote or upgrade ideas for new food products to ensure that from the earliest stages, engineering and technology solutions are aligned with the goals of green growth and sustainable development. By focusing on the greener ideas, the food products can take lower carbon products, water use efficiency and energy efficiency into account in their products' ideas to promote conservation of water and energy resources. To solve practical problems, instead of opting conventional solutions, food engineers can think about environmental-friendly alternatives, recyclable resolutions, waste-free products, thus food engineers can emphasize the efficient use of materials and contribute to sustainable practices early in conceive phase of products. If the operation (production, distribution, consumption) of the product has any impact on the environment, freshwater resources, land resources, forests or marine ecosystems in the future, food engineers can direct their ideas towards solutions that do not harm the environment, protect ecosystems and biodiversity, and promote a circular economy in which inputs are adopted aligned with the natural asset base indicators.

To develop a new idea, food engineers can invest in concepts that emphasize the environmental quality of life. They can direct their creativity and innovative solutions to improve both human well-being and environmental sustainability, contributing to a more harmonious and balanced life. In addition, inventors can develop technologies and products that actively contribute to improving air and water quality, solving pollution and waste problems, preventing risks and mitigating disasters - all of which always affect people in recent times and are their concerns.

By evaluating ideas in the context of green growth and sustainable development, which involves refining and enhancing concepts with the keys set out in GGIs, a food production project will not only meet current requirements but also future-proof evolving sustainability standards. A thorough evaluation of ideas using GGIs helps identify and rectify potential errors in the design and implementation phases. This proactive approach minimizes the risk of overlooking critical sustainability issues, fosters innovation, resilience and a proactive approach to sustainability, and contributes to the creation of food products that better meet the evolving needs of sustainable development.

Integrate Green Growth into the Design phase

In the product design phase, GGIs can play a crucial role in promoting and upgrading sustainability by guiding the decision-making process. GGIs can be used effectively to improve food product design while encouraging designers to focus on technologies and materials with lower carbon emissions per unit of output. Quantifying consumed resources including raw materials and energy-related greenhouse gas emissions using carbon footprint calculators is a method that creates opportunities to reduce carbon intensity in products plan process. With eco-friendly alternatives, recyclable materials, reduced waste generation designs or ready-reuse designs, food engineers can emphasize the efficient use of materials and contribute to sustainable practices early in design phase of products. Additionally, engineers can explore materials and ingredients and technologies that support carbon sequestration, such as using resources from sustainable forestry or incorporating carbon-absorbing, carbon-storing materials into product or packing design.

During the design process, food engineers can assess the impact of their products on freshwater resources, soil quality, biodiversity and marine environments to prevent harm from the manufacture or use of a product by employing alternative, more sustainable designs. Even in the design of the products themselves, engineers can incorporate environmentally friendly designs that help users to eliminate or reduce their environmental risk during product consumption or at their disposal. Additionally, in the case of product operations that involve water consumption or degradation of soil quality, engineers can design their food products components that are related to usage and conservation of freshwater and soil, both manufacturing processes and product use. Furthermore, considering products adaptability can include designs that take into account climate fluctuations or evolving ecosystem dynamics and minimize disruption to ecosystems and biodiversity. By integrating these GGIs-led considerations into the design phase, engineers contribute to the overall goal of sustainable development for the environmental quality of life.

By developing and optimizing new EEPs, including adopting renewable energy trends and minimizing energy consumption during the manufacturing, use and end-of-life phases, the food products are ready to participate in GCE. Furthermore, R&D activities focus on green technologies to commercialize products that promote a socially responsible approach with the creation of new green jobs and are in line with the SDGs. By integrating the economic opportunity and policy response indicators into the design process, food designers can create products that not only meet current sustainability standards but also align with future economic and policy expectations.

Integrate Green Growth into the Implement phase

In the implementation phase of food projects, GGIs can be integrated to guide and assess the execution of sustainable practices. Sustainability of employees is about enhancing workforce productivity that ensures fostering a culture of efficiency and labor-intensive tasks are

optimized by reducing the overall environmental impact per unit of production. In addition, when implementing projects with building a culture of organization that promotes and supports sustainable and labor productivity, value-adding tasks are also considered that make a positive contribution to environmental and social aspects and invest in the well-being of people.

The food projects might also take into account policy responses for sustainable development as well as economic opportunities. Some examples include: establishing job opportunities that align with the principles of green growth; investing in research and development that emphasizes green technologies and sustainable practices, or implementing the outcomes of the aforementioned process; working with environmentally sustainable projects and businesses, and joining a network of organizations that are exhibiting positive environmental and social performance with green growth principles; and, if feasible, implementing carbon pricing mechanisms to account for environmental externalities.

Integrate GGIs into the implementation phase, food projects can ensure that sustainability considerations are embedded in the execution process, contributing to overall green growth objectives. Through the practical application of GGIs to monitor and evaluate adjustments and improvements throughout their CDIO project, engineering students can engage in real-world projects and gain hands-on experience with a deep understanding of green growth principles and how these can be translated into practical measures.

Integrate Green Growth into the Operation phase

During the operation phase of food projects, the integration of GGIs is crucial to ensure sustainability and minimize environmental impact. Based on GGIs framework, food engineers could continue to collect relevant data and monitor the ongoing performance of the project in terms of environmental impact, resource efficiency and other sustainability criteria. In addition, assessing and optimizing energy, water and resource efficiency over the life of the project allows food engineers to conduct ongoing life cycle assessments, taking into account the entire life of the project. On the other hand, engineers can identify negative environmental impacts during the operation phase and take corrective measures in a timely manner. Through practice, food engineering students gain hands-on experience in implementing and maintaining sustainable technologies, as well as making adaptive adjustments based on GGI data to ensure the project remains aligned with sustainability goals over time.

CASE STUDY

Every student enrolled in Duy Tan University's CDIO@FT program must complete a final project that is planned and carried out in groups. Instructors then use rubric with assessment components to evaluate the projects. Through the integration of green growth and the circular economy, the project is assessed for sustainability with regard to people, the environment, and society in addition to the Conceive-Design-Implement-Operate criteria in this evaluation table. Throughout the entire ideation and project completion process, CDIO approach and GGIs have been utilized to give students a thinking scaffold as well as the drive to improve their concepts and streamline the project implementation procedure.

Case study 1

In order to determine a production process for beetroot wine using Saccharomyces cerevisiae yeast, the project with initial tiles is "Study on the Production Process of Beetroot Wine Using Saccharomyces Cerevisiae Yeast", aims to investigate the variables affecting the fermentation

process. The project was scheduled to be carried out in laboratory and involved five steps: Analyze the chemical and microbiological makeup of beetroot; Establish the ideal temperature and duration for sterilization; Determine the appropriate concentration of sugar, pH, and yeast ratios; Examine the effects of fermentation duration on quality; and Assess the sensory and microbiological qualities of the finished product. A standardized method for making beetroot wine would be created, considering all important variables influencing fermentation, and the finished product was assessed for quality, safety, and consumer acceptability. These are the anticipated results of the project.



Figure 6. Beetroot: The original root, juice and produced wine

Through the use of mentioned tools kit to promote or upgrade ideas and throughout the project, CDIO approach and GGIs were utilized to develop these goals. The project was tiled as “Development of a Closed-Loop System for Beetroot Wine Production with Enhanced Nutritional and Functional Value” with the main goals were to design a closed-loop system for beetroot wine production, optimize the production process for increased nutritional and functional value, and carry out a thorough analysis and evaluation of the system. To produce beetroot wine, the project successfully designed and implemented a closed-loop system, proving that this method is feasible for producing food in a sustainable manner. Furthermore, creative methods for maximizing resource use and reducing waste production were created for beetroot pulp and fermentation by-products. A superior product with more health advantages was produced as a result of the production process being optimized to improve the beetroot wine's nutritional and functional value. Its economic and environmental sustainability was demonstrated by a thorough analysis and evaluation of the system, underscoring its potential for broader food industry adoption.

Case study 2

The goal of the project with initial tiles is "Research on Producing High-Protein Vegan Floss from Oyster Mushrooms" is to create a high-nutrient vegan food product. The study emphasizes the rising popularity of vegetarianism in Vietnam as well as the need for easily accessible vegan goods that respect environmental and health concerns. The selection of oyster mushrooms was based on their high protein content, texture, and nutritional advantages—such as their high vitamin and mineral content and low fat and carbohydrate content. The expected outcomes include the establishment of an ideal procedure for producing high-quality vegetarian floss and thorough assessments of its nutritional and sensory attributes.



Figure 7 Developing of a high-protein vegan floss product using oyster mushrooms

The process of re-thinking concepts, creating experiments, putting the product creation process into practice, and running it has all incorporated the GGIs set and CDIO approach. Improvements to the project are evident when it concentrates on creating a wholesome and sustainable vegan floss product with oyster mushrooms, which fits in with Vietnam's rising vegetarianism and health consciousness. In order to minimize environmental impact and maximize resource utilization, the project combines the principles of Green Growth and the Circular Economy. Its goals include: developing a high-protein vegan floss product using oyster mushrooms that are sourced locally; optimizing processing methods (soaking, shredding, mixing, and drying) for quality, protein retention, and minimal environmental impact; making efficient use of resources, minimizing waste and energy consumption throughout the production process; investigating and putting into practice strategies for the valorization of by-products generated during mushroom cultivation and floss production; designing packaging and distribution systems that conform to circular economy principles, encouraging reuse and recycling; and evaluating the production process's environmental impact, taking into account factors such as energy consumption, water consumption, and waste generation.

The findings included the creation of a thorough report on the nutritional and sensory qualities, the design of an optimized process for producing high-quality vegan floss with little environmental impact, the development, application, and evaluation of waste reduction and value-adding strategies, as well as an assessment of the production process's environmental impact.

CONCLUSION

In conclusion, integrating GGIs into the CDIO framework, as demonstrated with the CDIO@FT program at Duy Tan University, offers a transformative approach to engineering education across various disciplines. This synergistic framework not only aligns with the global shift

towards sustainable development but also provides a measurable and actionable way to equip future engineers with the skills, knowledge, and mindset necessary to become responsible and environmentally conscious professionals.

While the CDIO@FT program showcases the specific application within food technology, the integration of GGIs holds immense potential for other CDIO@ET programs as well. By embedding sustainability considerations into each phase of the CDIO process – Conceive, Design, Implement, and Operate – engineering programs across various disciplines can foster a holistic understanding of green growth principles and empower students to create innovative solutions that address the complex environmental challenges of our time.

GGIs bring a unique value to CDIO@ET programs with providing a structured framework for incorporating sustainability into every stage of the engineering process, regardless of the specific discipline. Moreover, this integration connects engineering education to real-world sustainability challenges relevant to each field, such as renewable energy development, sustainable manufacturing, and green infrastructure. Fostering a holistic understanding of the interconnectedness of environmental, social, and economic factors in sustainable development across different sectors is also an advancement. By this method, the program equips students with the practical skills to assess, monitor, and improve the environmental performance of their engineering projects, regardless of their specific focus.

GGIs integrated CDIO@ET programs across various disciplines can cultivate a new generation of engineers who are not only technically proficient but also deeply committed to ethical and sustainable practices. These future leaders will be prepared to drive innovation and shape a future where engineering solutions contribute to a healthier planet and a more sustainable society. This integration is not merely a curriculum enhancement; it is an investment in a future where technology and society harmoniously coexist with the environment.

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INTEGRATING SENSE LAB AND PROJECT-BASED LEARNING IN LIGHTING DESIGN EDUCATION

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ABSTRACT

Traditional lighting design courses rely solely on classroom lectures, leaving students unable to experience and perceive light in real-world contexts. This research focuses on "Integrating Specialized Lighting Teaching Facilities with Project-Based Learning (PBL) " as a teaching practice study, elevating the "Lighting Design" course to a design practice-oriented curriculum. The course structure simulates the various stages of the lighting design process and incorporates the PBL methodology grounded in the CDIO framework. CDIO represents "Conceive," referring to the analysis of current needs and encouraging students to employ divergent thinking to address challenges; "Design," where students conceptualize solutions from a user-centric perspective; "Implement," involving the transformation of solutions or designs into prototypes, encompassing solution validation and production; and "Operate," focusing on continuous adjustments and testing to refine outcomes or projects based on real-world application. The CDIO framework helps train students to solve real-world lighting design problems.

The course also uses Feng Chia University's "Sense Lab" as a teaching field, where students utilize adjustable lighting systems and equipment to learn specialized lighting terminology and experience diverse lighting scenarios. In the PBL segment, students develop "light boxes" and "lighting design projects" as assessment tools to demonstrate learning outcomes. The course fosters integrated learning through case discussions, DIALux EVO lighting simulation software, and final project presentations. This innovative curriculum addresses the traditional emphasis on theoretical instruction in lighting design courses, enhancing hands-on experiential learning. Feedback collected through end-of-term surveys indicates significant improvements in students' understanding and application of lighting design, aligning with the project's anticipated goals.

KEYWORDS

Project-based learning (PBL), lighting design, Sense Lab, action research, Standards: 2,5,6,7,8

INTRODUCTION

"Lighting design" is an essential foundational knowledge in architecture and interior design. The course aims to equip students to effectively utilize light in spaces to fulfill functional and aesthetic requirements. To achieve this, students must possess a solid understanding of optical and physical principles and an appreciation for spatial design aesthetics, enabling them to excel in lighting design.

However, traditional lighting design courses often focus primarily on theoretical content, covering basic optical concepts, characteristics of light sources and fixtures, lighting methods, illuminance calculations, and spatial lighting case studies. Due to limited teaching resources and facilities, most courses rely on diagram-based explanations, leaving students with minimal opportunities to experience light in real spatial contexts or engage in hands-on lighting design projects. This theory-centric teaching model restricts students' ability to apply their knowledge in practical design and implementation.

Lighting design should not remain confined to traditional lectures, nor should its outcomes be limited to visually appealing renderings. This study advocates for integrating theoretical knowledge with practical application to enhance the teaching effectiveness of lighting design courses. This approach aims to enable students to comprehensively understand the application of light, acquire the expertise to evaluate the simulation effects of lighting designs, and professionally assess the quality of luminous environments.

How can "Lighting Design" transition from a purely theoretical course to one oriented toward practical application in design? Achieving this requires students to actively explore and investigate problems and engage in deep critical thinking throughout the learning process. Scholars have noted that incorporating "Design Thinking" and "Problem-Based Learning (PBL)" into cornerstone courses can enhance and sustain students' interest in engineering, motivate them for advanced coursework, increase hands-on experience, and improve their performance in integrated design courses. This approach addresses the gap between theory and practice in engineering education, enabling students to develop higher-order skills such as applying knowledge, analysis, synthesis, and evaluation (Dym et al., 2005).

In collaboration with TU Delft, Feng Chia University established the first subtropical "Sense Lab," an innovative teaching and research facility focused on environmental comfort and human perception, encompassing light, airflow, acoustics, and psychological well-being (Figure 8). The "Experience Room" on the first floor of the Sense Lab features lighting that



Figure 9. Sense Lab: Control and Experiential Exploration of Lighting

allows precise control of various lighting conditions. All fixtures' luminance and color temperature can be independently adjusted using dedicated dimming software, facilitating experiments and experiential learning. Additionally, the basement's small-scale "Light Chamber" is equipped with LED panel lights, linear strip lights, and spotlights, enabling the creation of various lighting scenarios. This setup supports various educational and research purposes, integrating furniture arrangements and relevant instrumentation.

By integrating the Sense Lab into the lighting design curriculum, students gain hands-on experience in controlling and experiencing diverse lighting scenarios, significantly enhancing their understanding of lighting principles and their practical application. This study aims to leverage the Sense Lab as a teaching environment, incorporating CDIO and PBL into project-based coursework. The CDIO' Integrated Learning' model allows students to engage with multiple small projects, progressing from basic to advanced levels. This approach fosters critical decision-making skills, enhances student interest, and improves learning outcomes. Practical projects, combined with the Sense Lab as the lighting teaching environment, enable students to develop their knowledge, operation, and evaluation of light effectively.

METHODOLOGY

CDIO

The CDIO engineering education design concept was co-founded by the Massachusetts Institute of Technology (MIT) in collaboration with Chalmers University of Technology, Linköping University, and the Royal Institute of Technology in Sweden. It is a novel educational framework based on the product lifecycle process to comprehensively enhance students' foundational competencies (Crawley, 2014). This framework promotes holistic development in foundational knowledge, personal skills, teamwork, communication, and systems thinking. Particularly in engineering systems capabilities, it emphasizes using knowledge to create value for society through innovative processes of conceiving, designing, implementing, and operating within corporate, societal, and environmental contexts. The core definition and principles of CDIO are summarized as follows (Crawley, 2007):

- Conceive: Analyze problems and define needs based on understanding societal and market demands, then propose conceptual designs for solutions.
- Design: Developing detailed technical and design specifications based on the conceived solution, integrating innovative elements into the concrete design.
- Implement: Transforming the design into practice, including manufacturing, testing, and refining prototypes.
- Operate: Deploy the designed system in real-world settings and continuously monitor and improve its performance and impact.

The primary goal of the CDIO framework is to cultivate students' ability to apply knowledge in real-world contexts. This prepares them to excel in diverse engineering and societal challenges and contribute to corporate and social development within a globalized context.

The 6th standard of CDIO emphasizes the importance of the engineering laboratory. The successful implementation of CDIO requires an academic environment that provides appropriate workspace, facilities, and tools, collectively known as the engineering laboratory. These spaces must support the entire project process—conceiving, designing, implementing, and operating—across simple and complex individual and group projects. In parallel, relevant infrastructure is developed to promote an active, hands-on learning approach. The

laboratories play a key role in demonstrating the significance of the environment to students and enhancing their education. The engineering laboratory serves as a crucial space where students can engage in creative and practical learning experiences. Moreover, the laboratory is an integrative, practical venue that supports the entire curriculum planning, distinguishing it from traditional labs（Guo et al., 2012）.

Problem-based learning (PBL)

Problem-Based Learning (PBL) was first introduced by McMaster University in Canada as a teaching and learning method centered on solving real-world problems. Project-Based Learning (PBL) builds upon the principles of inquiry-based learning, enabling students to construct their knowledge systems through the investigation and research of problem-solving projects, which they can then apply in real-world scenarios. Project-Based Learning consists of four key elements: content, activities, context, and outcomes. Content is derived from real-life problems characterized as complex, unpredictable, and interdisciplinary knowledge. Activities primarily refer to students' problem-solving actions. Context refers to the environment that supports students in conducting exploratory learning. Outcomes are the knowledge or skills students acquire during or at the end of the learning process, such as collaborative learning skills, life skills, and self-management abilities (Zhai et al., 2018).

Problem-Based Learning (PBL) is characterized by several key features (Chen, 2012). It focuses on problem-centered learning, where students collaboratively collect, analyze, and discuss information to solve problems. The group-based learning model fosters effective problem-solving through interaction and shared experiences. Discussions are central to the process, encouraging critical analysis and development of solutions. PBL emphasizes active learning, requiring students to set objectives, assess their abilities, and engage in self-evaluation. Teachers act as facilitators, guiding discussions and providing feedback to enhance problem-solving and critical thinking.

PBL is designed based on practical and theoretical needs to motivate learners, guiding them to understand, apply, and create knowledge. Additionally, learners can construct or interpret information through experiential learning, case studies, or knowledge sharing (Tiong, 2004).PBL emphasizes critical thinking, learning how to learn, and collaborating with others. These processes empower students to become autonomous, skilled, and self-discovering, enhancing teamwork skills and spirit. Due to these characteristics, PBL is widely applicable across various student groups and disciplines (Valdez et al., 2009).

TEACHING PLANNING

The course objectives of "Lighting Design" include defining and describing the basic knowledge of optics and identifying various types of lighting sources and lighting systems as the basis for lighting design. Be able to recognize, analyze, and appreciate the aesthetics of spatial lighting design and translate this into personal ideas about lighting design; apply lighting design principles; use appropriate lighting techniques for different types of spaces; and sum up ideal solutions.

The teaching theme is combined with the teaching concept of CDIO to transform PBL-oriented learning further. CDIO stands for "conceive," which refers to the analysis of current needs and encourages students to use divergent thinking to try to solve the challenges and problems they face; "design," which means that students must use the perspective of the demander to conduct Design is the process of outlining a solution; "implementation" refers to the process

of students converting a plan or design into a "prototype," including plan confirmation and production, which means the presentation of the design; "operation" refers to students The team or designer achieves satisfactory results or works based on the experience presented, through continuous revision and testing.

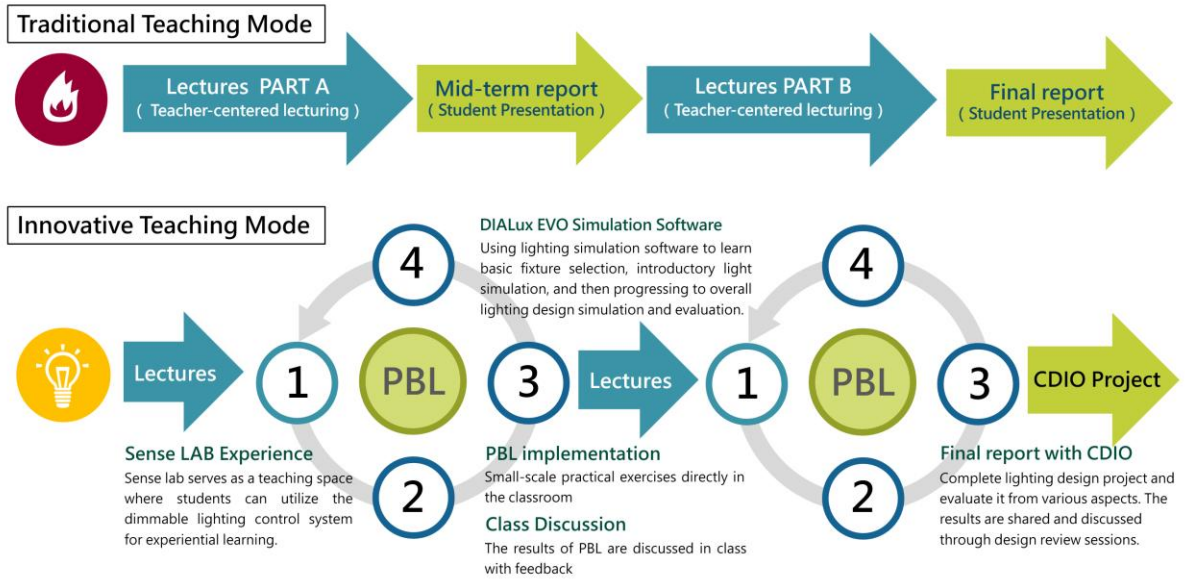


Figure 2. The difference between the innovative teaching mode and the traditional teaching mode of the "Lighting Design" course

This study compares classroom teaching units with various stages of the lighting design process and introduces CDIO course-specific practices to enhance student learning outcomes. PBL will be implemented as a teaching unit for several small, "design-oriented topics." Throughout the learning and operational phases at each stage, students will observe the progression of each lighting design process and simultaneously acquire the necessary knowledge and skills for each design stage. These professional skills will be applied to address complex lighting design projects (Figure 2). Students will also learn how to use different materials and lighting in the lighting control system of the Sense Lab, gaining hands-on experience in controlling and understanding light.

The research is organized into three stages: pre-teaching preparation, classroom teaching, and effectiveness evaluation, as illustrated in Figure 3. The "action research method" in this course uses questionnaires, scales, and student work as data collection tools. Quantitative data are analyzed using statistical methods, while qualitative data, such as feedback on changes in learning motivation, self-learning attitudes, and course acquisition, are gathered through unit feedback questionnaires. These qualitative responses serve as the primary data for the study. Over the semester, teaching follows the unit schedule, incorporating field teaching and special projects into the curriculum. Mid-semester formative assessments are conducted, and a post-questionnaire is administered at the end of the semester to allow students to self-assess their learning performance and outcomes. Special reports are evaluated using a rubric rating scale. Finally, all course materials and questionnaire results are subjected to statistical analysis.

A "direct assessment" method evaluates student project achievements, utilizing Rubrics for scoring. The "indirect assessment" method involves pre-test and post-test evaluations, with questions designed based on the course's core competencies. The questionnaire also

examines whether the teaching environment supports learning across various lighting topics. Additional reference assessment methods include tools such as the "midterm formative assessment" and "summative assessment" within Feng Chia University's iLearn 2.0 system.

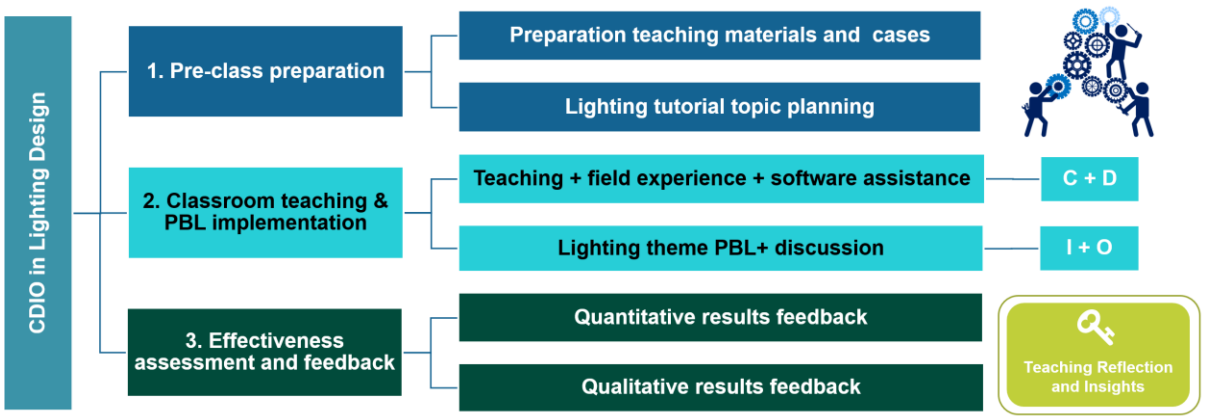


Figure 3. Three-stage research method

TEACHING IMPLEMENTATION

The subjects of this study were third-year students of the Interior Design Program of the School of Architecture. The data collected were the question-and-answer records, questionnaires, and homework in class. The class and research location were the "Experience Room" (1F) of the Sense Lab of the School of Architecture. And "Light chamber (B1)". The "Lighting Design" course scope can be divided into several central units, including "Lighting Principles and Visual Perception," "Light and Space Composition," "Lighting Environment and Psychology," "Light Sources and Lighting Forms," and "Lighting Simulation and Evaluation." The main teaching methods include classroom lectures, PBL topics, and lighting field teaching.

Classroom teaching

Through lectures, students were systematically introduced to the fundamental principles of optics, evaluation methods, and instrument operation techniques. In the classroom, students were encouraged to engage in critical thinking, ask questions, and receive timely supplemental explanations to enhance their understanding of the course content. Teaching strategies and resources such as Kahoot, Slido, and other Interactive Response Systems (IRS) were utilized to foster direct student interaction, allowing immediate feedback and active participation through questioning. These methods contributed to a more dynamic and engaging learning environment.

Lighting field teaching

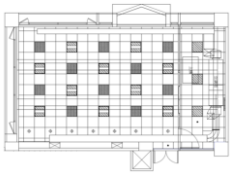
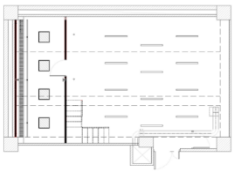
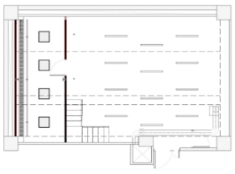
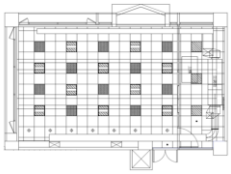
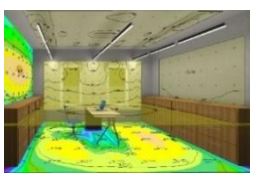
The course uses the Sense Lab's " Experience Room " as the classroom and uses the lighting control system to explain lighting design techniques. It also provides a " Light chamber " for students to operate light in practice and complete the projects.

Project-Based Learning

The course is designed as teaching modules incorporating PBL, requiring the application of the CDIO process to complete projects. It integrates the college's Sense Lab as a teaching platform into a structured teaching design spanning five progressive stages (Table 1).

Unit 1 covers professional lighting terminology and field lighting quality assessment. Students learn the definitions of terms and lighting environment standards, and they use optical instruments to evaluate the lighting quality of the Sense Lab, followed by group discussions and presentations. Unit 2 involves a "Light Box Experiment" where students select a "light & atmosphere" theme and design a 30cm cardboard box. They arrange the box's interior using various openings, shapes, colors, and materials, then use Sense Lab light sources to create lighting scenarios, then discuss the resulting lighting effects and shadows.

Table 3. Course Schedule and Instructional Design

PBL	CDIO	Field of use	Course Content	
【 Unit 1】 Lighting Design principles	C			• Teach lighting design principles and the use of instruments • Introduce Sense Lab
【Unit 2】 Lightbox experiment	CDI			• Practice light and shadow in scaled spaces • Use Sense Lab lighting to assist in lightbox photography
【Unit 3】 Lighting control and experience	CD			• Utilize the Sense Lab lighting control system • Experience firsthand how changes in lighting affect perception
【Unit 4】 Lighting scenario	CDI			• Utilize luminaires and furniture to achieve lighting scenario design • Use the Sense Lab lighting control system
【Unit 5】 Lighting Design and Simulation	CDIO			• Use simulation software DIALux to complete the lighting design project • Use Sense Lab for assistance

Units 3 and 4 use the Sense Lab lighting control system, allowing students to familiarize themselves with lighting fixtures and control the light to experience the changes in lighting. Students then challenge each other with tasks to adjust the lighting to the required scenarios. Unit 5 is the final review, where students learn to use DIALux EVO lighting software with assistance from the Sense Lab environment. They then design residential lighting using DIALux and present their results for discussion.

ANALYSIS OF TEACHING OUTCOMES

Course Objective Achievement Status

Feedback from classroom interactions and surveys indicates that students widely acknowledge Sense Lab as an effective platform for lighting education. The project-based learning approach within Sense Lab has notably enhanced their understanding of lighting design. Table 2 presents the alignment between course objectives and core competencies, integrating teacher self-evaluation and student feedback. According to student responses, the teaching effectiveness closely matched the course objectives outlined in the syllabus, with evaluation scores ranging from 4.50 to 4.75(5 being the best).

Table 2. Achievement of the objectives of this course

Course Objectives	Course objectives achieved (teacher self-evaluation)					Student Feedback
	Very Easy	Easy	Medium	Hard	Very Hard	
1. Be able to define basic lighting knowledge as the basis for lighting design		V				4.75
2. Be able to recognize, analyze, and appreciate the spatial aesthetics of lighting design, and be able to develop personal lighting design ideas			V			4.50
3. Be able to apply lighting design principles and summarize ideal lighting design solutions			V			4.75

Student Learning Feedback

Student learning feedback was collected through a questionnaire, where students self-assessed their learning outcomes for each of the PBL units (Unit 1 to Unit 5) on a scale of 1 to 5 (with 5 being the best). The results showed that the highest rating was for Unit 3, focusing on lighting control, with a 4.7 (Figure 4). This indicates that the controllable lighting features of Sense Lab provided students with a profound learning experience. The second-highest score was for the final integrative project, "Lighting Design and Simulation," with a score of 4.6, reflecting positive learning feedback from students regarding the DIALux lighting project at the end of the semester.

Figure 5 shows that students strongly believe Sense Lab enhances their learning outcomes, with 60% strongly agreeing and 40% agreeing. Similarly, 60% of students strongly agree, 36% agree, and 4% are neutral on the effectiveness of PBL in improving their learning experience. Overall, 51% of students agree, and 45% strongly agree that the lighting design course has significantly enhanced their learning outcomes. These results indicate that students strongly affirm the effectiveness of integrating the teaching environment with project-based learning in this course.

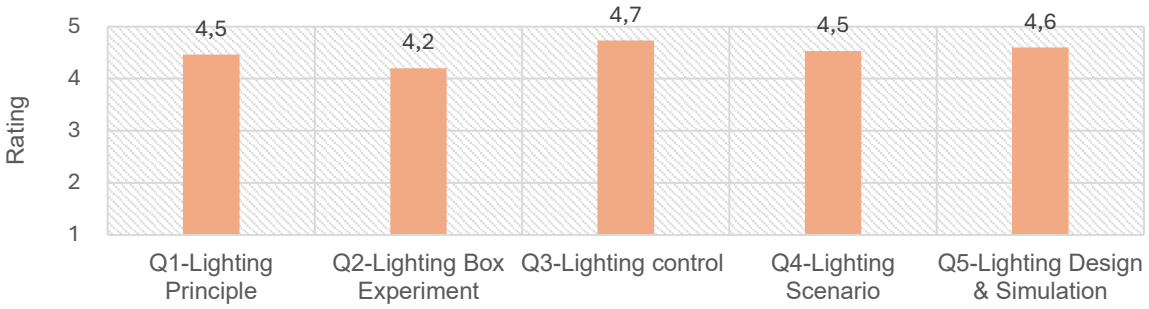


Figure 4. Student self-assessment questionnaire: Learning Outcomes of PBL & Sense Lab

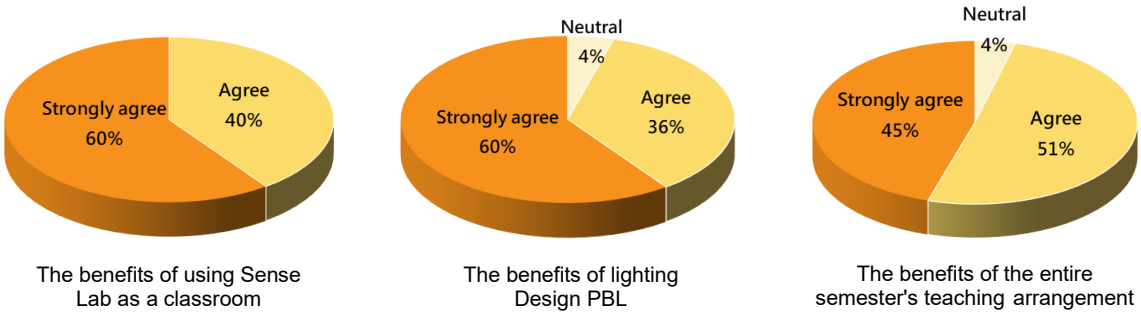


Figure 5. Students' feedback on learning outcomes

CONCLUSION

Lighting design can be a practice-oriented course that solves real problems. This semester's "LightBox" and "Residential Lighting Design & Simulation " use CDIO thematic operation methods. Classroom discussions and practical activities help improve students' professional knowledge, core abilities, classroom participation, and learning satisfaction. In addition, instant debate and feedback on the finished work in class are very helpful to students. Therefore, this year's teaching experience and research results show that lighting teaching that combines laboratory fields with practical projects can indeed help improve learning outcomes; CDIO project-based learning can also help enhance students' ability to apply knowledge.

There are two suggestions for implementing relevant curriculum planning in the future: (1) The teaching field should correspond to the content of the topic practice, and more themes can be designed to effectively use the space hardware and software equipment to diversify and improve teaching effectiveness; (2) Improvements in methods for assessing student learning outcomes have specific implications for evaluating how teaching methods affect student learning outcomes, and further consideration of qualitative research methods and data collection methods are needed.

ACKNOWLEDGEMENTS

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BIOGRAPHICAL INFORMATION

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DEFINING CHALLENGE BASED LEARNING AND EDUCATION IN THE AUTONOMOUS SHIPPING CONTEXT

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ABSTRACT

The increasing digitalization and introduction of Maritime Autonomous Surface ships (MASS) is changing the role of seafarers and other professionals in the maritime sector. The technological complexity of ships due to automation requires the development of skills related to, for example, cybersecurity, ship equipment engineering, and software development. This results in a demand for strong problem-solving abilities, adaptability to technological changes, and continuous learning, which, in turn, requires maritime education and training to become more adaptive and responsive. This includes emphasizing lifelong learning, embracing an interdisciplinary approach, and promoting project-based and problem-solving learning methods. Challenge-based learning has been established as a successful method for delivering practical real-world learning experiences in engineering disciplines and it has been proposed as an evolution of the Conceive, Design, Implement and Operate (CDIO) framework adopted widely in universities giving engineering education. In this paper, we present concrete definitions for the concepts of challenge-based learning and education in the MASS context. Such definitions for MASS education have not been previously presented in the literature. The definitions will pave the way for successfully applying challenge-based learning in this field and serve as foundations for building educational frameworks for MASS.

KEYWORDS

Challenge Based Learning, Autonomous Maritime, Shipping, CDIO Standards: 1–3, 5–8

INTRODUCTION

The increasing digitalization and the introduction of Maritime Autonomous Surface Ships (MASS) are changing the role of seafarers and other professionals in the maritime sector. For instance, it has been revealed that MASS operation from remote control centers would require a different set of skills from seafarers compared to the current situation (Sharma & Kim, 2022). The need for detailed knowledge in a narrow field would be replaced by creativity and quick problem-solving skills, similarly to other highly automated sectors like aviation, mining and ports (Emad et al., 2022). Leadership has been mentioned as one of the critical skills for seafarers to learn in the future (Hynnekleiv et al., 2020), too, also with the introduction of MASS.

Many studies on the increasing automation and digitalization impact on maritime education and training highlighted the urgent need for new competencies in ICT, cybersecurity, automation, and smart shipping technologies (Bolbot et al., 2022; Cicek et al., 2019). In particular, Alop (2019) pointed to the need to manage and interact with advanced digital systems, understand complex human-machine interactions, and utilise big data analytics. Additionally, he specified the demand for strong problem-solving abilities, adaptability to technological changes, and continuous learning, which, in turn, requires maritime education and training to become more flexible and responsive. This includes promoting lifelong learning, embracing an interdisciplinary approach, and promoting project-based and problem-solving learning methods.

The need for interdisciplinarity in education for MASS has been noted, for example, in the study by (Mogensen, 2018). The study found that a good command of matrix calculus, required for marine engineers but not accommodated by STCW education, is needed for future seafarers in order to understand the systems architecture of discrete control systems. The use of interdisciplinary teams is also expected to create a beneficial learning environment. Interdisciplinarity in education can also address the risks of errors during human-automation interactions, which are often discussed in the MASS context (Ahvenjärvi, 2016; Hogg & Ghosh, 2016).

In this paper, we formalise concrete definitions for the challenge-based learning and education (CBL and CBE) concepts in the context of MASS. While CBL and CBE have been discussed as viable learning and education strategies to promote interdisciplinarity and the application of theory to practice, a concrete definition of these concepts for the educational needs of MASS has not been previously presented. Challenge-based learning has been established as a successful method for delivering practical real-world learning experiences in engineering disciplines as reported by, for example, by Malmqvist et al. (2015). More recently, CBL and CBE have been identified by Rådberg et al. (2020) as an evolution of the Conceive, Design, Implement and Operate (CDIO) framework adopted widely in universities giving engineering education. In maritime education, CBL and CBE have been highlighted as a way to address the growing need for inter-disciplinary knowledge and the development of 21st century skills like critical thinking, problem solving, digital literacy, creativity and communication (A. R. Morariu et al., 2025).

We consider that CBL and CBE, when properly defined for the context, have the potential to address MASS needs because of their fundamental principle: students define the challenges, rooted in real-life contexts, and then attempt to solve them. Such an approach calls for critically analysing the situation at hand, developing communication skills and keeping learning close to the real-life challenges in the maritime sector. Since the challenges to be solved are defined as part of the learning process, it allows for accounting for the changing context in the maritime sector.

The development of the CBL and CBE definitions derived in this paper was commenced in the AutoMare EduNet project funded by the Ministry of Education and Culture in Finland during 2021-2023. In AutoMare EduNet, a multidisciplinary collaboration network between universities was built to ensure the delivery of high-quality education to meet the emerging educational needs of MASS.

DEFINITION OF CHALLENGE BASED EDUCATION AND LEARNING

Challenge Based Learning (CBL) shares similarities with Problem-Based Learning (PBL), as both engage students in solving real-life problems. PBL does not focus on the problem or how it is handled, but rather on the achieved knowledge and intended learning outcomes. The PBL model has existed for decades, but CBL has been introduced more recently. CBL aims to incorporate 21st-century skills, such as critical thinking, problem-solving, and technological competence, into PBL and integrate technology into the process. CBL's primary goal is for students to develop practical, real-world solutions to open-ended problems called challenges, not just to complete a critical thinking exercise. This renders CBL a natural extension of the previously existing methods like PBL.

In Challenge-Based Learning, students achieve a deep learning experience by solving real-world challenges. The challenges are sociotechnical and multidisciplinary, and they do not have an exact predictable outcome (in comparison to problems with expected solutions). The challenge solving process determines the direction the solution will take. Student groups define the details of the initial challenge and identify the knowledge needed to tackle the challenge and progress towards a solution. In the AutoMare project, CBL is applied as a pedagogical paradigm rather than used as the implementation style for each course. As such, in the AutoMare context, we use the term Challenge Based Education (CBE).

In CBE, we can identify three main phases:

1 **Engage**: start from the conceptual challenge and proceed to define a concrete and actionable challenge.
2 **Investigate**: apply and acquire knowledge and skills to conduct activities that lead towards possible solutions; simulations, experiments, research and subprojects.
3 **Act**: develop and implement solutions in an authentic real-world environment, and evaluate the obtained solutions and results.

CBE is already reflected in the teaching of courses related to the design of advanced (autonomous) ship concepts and the analysis of risks of autonomous technologies at Aalto University. Courses such as Principles of Naval Architecture, Ship Design Portfolio, and Marine and Ship Systems Engineering enable a teaching and learning experience with M.Sc. students in the development of a new ship concept in a project/assignment. Other courses such as Marine Risks and Safety teach the composition and management of the safety-critical systems for enabling maritime ship operations. This is particularly critical for MASS as this demands an understanding of the functioning of the onboard and onshore systems which requires the incorporation of multiple safety viewpoints and interpretations. In these courses, the students engage better with real-life challenges, and the courses have supported collaboration in a multidisciplinary way. In addition, students are capable of exploring, discussing, and meaningfully constructing concepts and relationships in contexts that involve real-life challenges and projects

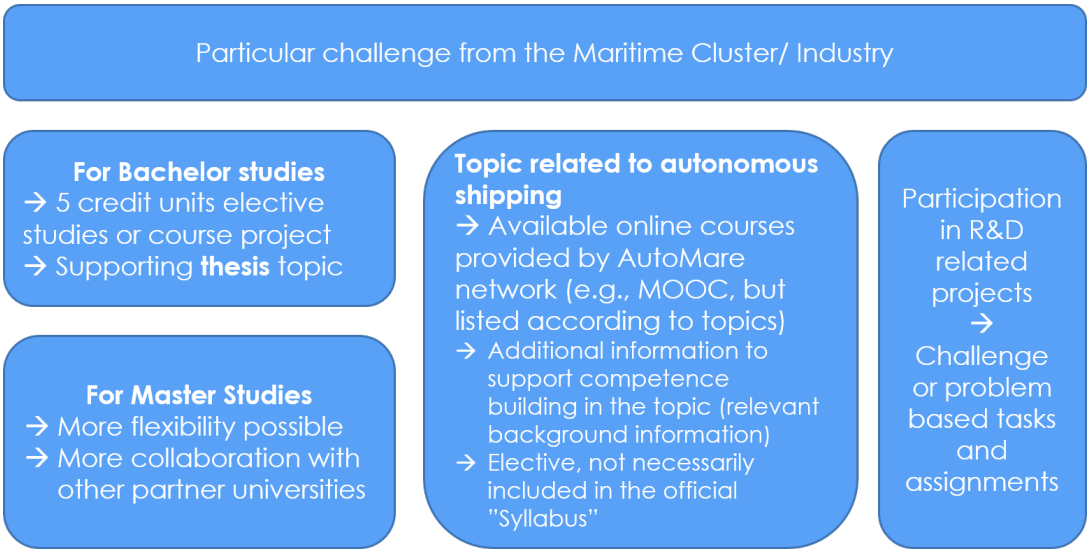


Figure 1. Integrating challenges to education and degree programs

(mainly with the industry) that are relevant to the learner. Overall, CBE at Aalto University has offered benefits such as establishing new teaching and learning practices that are better aligned with work-life environments and therefore can increase the students' employability.

CBE can, and in most cases, needs to be brought incrementally into the curricula of different educational institutes. Even though challenges are often extensive, some curricula may define a specific amount of challenge-based coursework to be included, meaning that the students following those curricula contribute to the challenges at some specific stage for some specific amount of work, but do not necessarily participate in solving the challenge from the beginning to the end. The same challenge can bring together students from different courses and disciplines. Figure 1 presents a proposal for integrating challenges to education and degree programs.

For a successful deployment of CBE in educational institutions, a close and continuous collaboration between them and stakeholders in the field is essential. For this reason, CBE as defined in the AutoMare EduNet project includes the innovative concept of AutoMare Challenges and Novelties Pool. The Pool is needed to ensure continuous challenge availability to student groups. Without continuous availability, delays in obtaining challenges can severely hinder the application of CBE as part of the educational offerings of different institutions. To create such a Challenges and Novelties Pool, real-world challenges need to be collected from the industry. This would conveniently be achieved by organizing regular workshops and seminars between instructors, students, and the representatives of the stakeholders and maritime industry to identify and disseminate challenges and relevant knowledge. The actual process for organising the Pool as a form of collaboration between educational institutes, stakeholders and industry would need to be defined by the collaborators in their joint co-operation planning. The ways in which CBE as defined in this paper fosters peer learning within student-instructor-industry collaboration is elaborated further in another CDIO 2025 paper by the authors (A.-R. Morariu et al., 2025).

In Finland, bachelor's degrees in maritime education are divided into two categories: degrees based on the STCW Convention (Seafarer Training), and degrees in which education is based

on marine technology and shipbuilding/design. The STCW Convention, which regulates the training of seafarers, is a mandatory convention that strongly regulates the content of maritime bachelor's degrees. Compliance in Bachelor's degree studies based on STCW is monitored and audited periodically by national authorities. The development of MASS training is strongly linked to the expected changes to the STCW Convention, the work that is about to begin in the International Maritime Organization (IMO) (Sandell, 2024).

For Master of Maritime Management degrees, the situation is very different. Master's degrees act as a bridge from sea to land, so that in the future, a growing number of people with experience at sea can work in the land organizations of the maritime cluster. For these, the skills requirements will increase in line with the requirements of increasing autonomy. The role of these persons, as shipping companies adapt to the changes brought about by autonomy, is essential for the development of the maritime cluster as a whole (Sandell, 2024).

Traditionally, minor subject students are studying the basics of the MASS field, sometimes even having different courses than the major students. However, with AI and autonomous technologies rapidly transforming the maritime field towards autonomous shipping, the role of minor students has significantly evolved. They are now central to this renewal process, making it essential to integrate them with MASS major subject students. This integration involves working together to define and solve challenges, as well as developing cooperation and communication skills. Often the minor subject students are from the ICT field, with key areas of focus including autonomous technology, artificial intelligence, data science, software engineering, interaction technologies, and cybersecurity.

In PBL, different subjects are integrated together in the curriculum. Based on this, the student can form topics that meet the working life needs during their studies and start developing their professional competence. PBL is described at two levels, micro and macro. At the micro level, activities take place in classrooms or online, allowing students to develop self-direction and teamwork skills. In order for PBL goals to be achieved, the actions of both the learner and the teacher must be reflected. PBL at the macro level is a strategy that should be reflected not only in the learner's behaviour but also in the curriculum, teaching and collaboration of the entire educational institution. The teaching of all subjects combined into a broad whole, simulating the operation of a company, is suitable especially for Bachelor-level teaching, where students are physically present. Continuous collaboration between all teachers is needed to advance and support the students' work; for example, in the fields of business, accounting, languages and law. On the macro level, all courses and lectures are integrated into PBL learning, where continuous company development and problem solving require the presence and close cooperation of each teacher. PBL at macro level can also be combined with CBE, and CBE based assignments can be part of macro PBL teaching strategy (Sandell, 2024). Given the uncertainty regarding the development of the maritime sector with a more abundant introduction of MASS, it is necessary to develop flexible teaching and learning frameworks, which would allow for agile adjustments and modifications according to emerging needs. Therefore, CBE is a method that enlarges the methodological choices compared to traditional PBL methods (Sandell, 2024).

Both PBL and CBE have their roles in the future of Maritime Education and Training (MET) when Education relating to autonomous shipping is being transformed and shared in Digivisio 2030 (a program involving all Finnish higher education institutions that aims to create a future for learning that benefits higher education institutions, learners and our society as a whole) starting in autumn 2025. As the Digivisio 2030 consortium of higher education institutes is developing

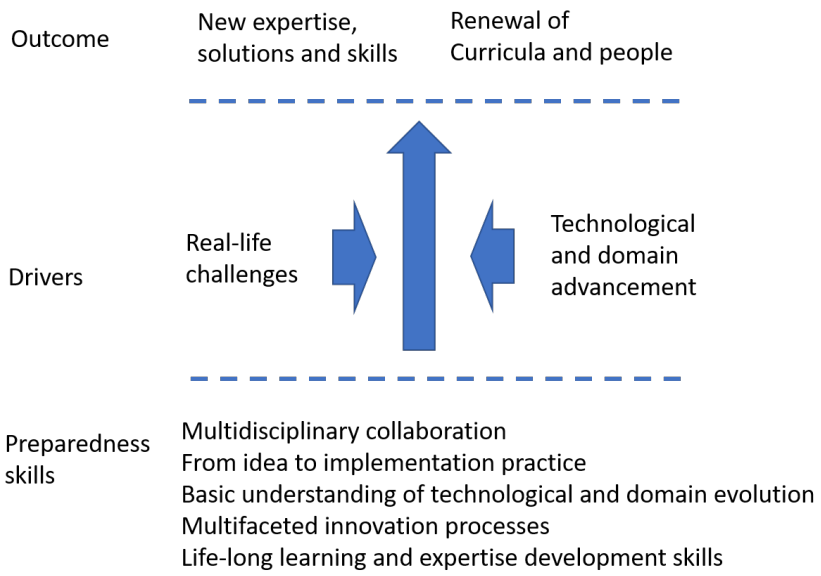


Figure 2. Challenge based education process

and relies more on cooperation of both institutions of more technological science Universities and the Universities of Applied Sciences which have the responsibility for MET for the STCW standards, it is evident that there are two approaches which need to be combined. MET is more strictly tied to education as it is strongly regulated by the STCW convention. Therefore, it is also more tied to solving problems on the basis of international regulation which determines the possibilities for solutions which are legally enforceable and which follow the IMO regulations and guidelines. CBE is suitable for the development of technological standards and solutions for how technological problems can be solved. As MASS Code will enter into force based on a goal-based instrument, both PBL and CBE will be suitable methods in their own practice areas. As autonomous shipping is strongly combining traditional seafaring with technology, the consortium will use both methodological approaches as the work continues. It is evident that the mixing of methods will develop new kinds of co-operations for the future of autonomous seafaring when the IMO standards are finalized (Sandell, 2024).

Readiness and preparedness of students and teachers for adopting CBE

There are three key elements in the CBE process: **1)** educational outcome, **2)** impacting drivers, and **3)** preparedness skills. The process is illustrated in detail in Figure 2 and discussed in the following. The development of technology and automation enables innovations from existing and new companies, and applications related to artificial intelligence are increasingly being seen. Artificial Intelligence can bring more value to maritime companies' decision making, operation optimisation and automating different tasks. For example, AI can be used in a ship's voyage planning and forecasting weather as well as in ship maintenance and fuel consumption optimisation. Artificial intelligence can also be utilised on board vessels in safety-related functions, such as behaviour-based safety, where the aim is to improve the shipping company's awareness of the safety culture on board. Other safety-related benefits can be seen in bridge systems and collision risk assessment, as well as fire risk detection. On the other hand, the use of artificial intelligence brings new risks and issues to be taken into account for the shipping company, such as cybersecurity, ensuring reliable data in AI analytics, and taking into

account the training needs of personnel and data protection. All this needs to be reflected in the intended learning outcomes of the educational curriculum.

Especially in technology, we have faced continuously disruptive or incremental transitions that impact and drive research, education, business, work-life balance changes. This in turn affects the required expertise and skills and intended learning outcomes. In the past, those impacts were very narrow, influencing specific fields or business areas, and lasted for limited time. Now in the AI era, the change will cover all fields and have very diverse impact. Also, one special dimension is the timeframe of change. The AI related changes are typically very fast and involving multiple fast sequential changes implemented over a long period of time. The scale is so massive that it is impossible to fill the expertise gap on a global scale using new recruitment. In the AI transformation process, we need to understand a) how technology/AI will develop, b) how this evolution impacts this field, c) what it requires as an expertise, and d) how this transformation can be implemented with a high diversity of expertise to be integrated. It is relevant for the students to learn how to use AI efficiently for their work and how to communicate with it. The role of AI is also changing and increasing in time. One problem is that AI technology is developing extremely fast. In this development, it is relevant to see how people are able to give added value to the work of AI staying competitive in the working market. CBE is a very natural approach for studying challenges and solutions relating to the AI transformation. One strength in this approach is also easy integration of several disciples together solving the problem and considering multiple angles in the solution.

To adequately prepare students for CBE, a diverse array of skills and knowledge tailored to each student's background and academic/work discipline is essential. Not every student needs to master all the skills required; however, each working group collectively should. Effective communication within the group is crucial, allowing students to share their expertise and contribute to solving the challenge. A solid understanding of technological development, its challenges, impacts, and the causalities in the domain characterized by digitalization, artificial intelligence, and robotization is an excellent starting point. In this context, we focus on maritime operations.

Students must establish a comprehensive and forward-looking vision of the domain and technology in order to effectively address the challenge in the right context providing sustainable solutions. Sustainability should be considered from environmental, technological, economic, and social perspectives. The vision-building process begins with an understanding of key technological trends and their implications for the field's development and the renewal of students' expertise. Challenges often require such a broad range of expertise that no single individual can possess it all. Therefore, learning to critically retrieve, analyze, and synthesize information and collaboratively produce new knowledge is a necessity in addressing multidisciplinary challenges. It is essential that students are able to go deeper into the content and see things from different peoples' angles, not only divide the work between each other. Students must be able to discuss their own topics and fields with others in student/layman's terms.

The process commences with defining the challenge and culminates in its implementation. For this process several concepts and platforms exist. For more than 10 years, the CDIO framework — Conceiving, Designing, Implementing and Operating systems and products — has been utilized to guide this process in the field of engineering (Malmqvist et al., 2020). Students benefit from preparing for a multifaceted innovation process or at least separately multifaceted approach and thinking, and innovation processes. It is essential to recognize that problems should not be approached from a single perspective; for instance, engineers should

not design systems solely from a technological standpoint aimed at other engineers.

The educational outcomes to the students clearly are the obtained new expertise and skills, and the reached sustainable solutions provided to the identified challenge. This also provides a platform for continued renewal of curricula and teachers' expertise. In general, when a challenge is approached from multiple perspectives by a multidisciplinary team, involving students, teachers and industry professionals, peer learning takes place. Participants will learn to see the challenge from a wider perspective, deepen their knowledge of the subject and also learn from each other. The role of the teacher is to enhance this kind of dialogue and open communication to harness the knowledge and competence of the team participants. Furthermore, even though the teacher is an expert within his/her subject field, it might be that the teacher will not be an expert of the whole context of the challenge. Therefore, the role of the teacher changes from teaching the actual subject to more of being the person who guides the actual challenge solving process operating more as a coach than a subject expert sharing information. In CBE, addressing the challenge needs to be consistent to ensure that the whole process is proceeding systematically from challenge formulation towards the wanted end result and an innovative solution, hence providing guidance, support and supervision, which requires preparedness from students and teachers alike.

In CBE, both the targeted end result and the main objective is an innovative solution. In the engineering education programs represented by the authors, students are prepared for embracing CBE by building on their ability to accept some levels of uncertainty is needed along with the ability to adapt as the process proceeds. This is achieved through individual and group work project courses where the assignments are open-ended and require the students to accept that a need for changes is likely to emerge. The outcome is students with a mindset for understanding that even though there are good plans made in the beginning, these might have to change according to situational needs. This also includes teaching methods and tools as well as the educational infrastructure where the teacher manages and guides the CBE process with different pedagogical methods and a multidisciplinary team where participants have different backgrounds. The CBE process is also a learning process for the teachers as well as for the students, which gives both an opportunity and a requirement for constant learning, adaptability and renewal.

CONCLUSION

In this paper, a systematic definition for challenge based education (CBE) in the autonomous shipping context was presented. We compared the new CBE definition with problem based learning. For CBE, we identified three main phases: 1) engage, 2) investigate, and 3) act. The presented CBE definition promotes multidisciplinary collaboration towards multifaceted innovation processes. We highlighted the importance of systematically building preparedness skills for students through their studies before they start identifying and solving real-life challenges. The outcome is to provide new expertise, solutions and skills, but it also gives an excellent opportunity for continued renewal of curricula and people. Even though this paper focused on the autonomous shipping context, the presented definition for CBE is generalizable to all engineering fields. Similarly as for autonomous shipping, major subject students from other disciplines have an important role in incorporating their technological substance through participation in the challenges to induce development and transformation in the primary field of engineering targeted by the CBE process in question.

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A CHALLENGE BASED EDUCATION FRAMEWORK FOR AUTONOMOUS SHIPPING

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ABSTRACT

Due to expected profound changes in the maritime industry caused by the introduction of Maritime Autonomous Surface Shipping (MASS), the education in this field is in clear need of development. Cross-sectoral and inter-disciplinary understanding of the premises of autonomous shipping is required of professionals connected to MASS design, construction and operation. There is a gap in aligning education to technological developments in MASS, as existing approaches fail to specify the type of training required or to propose a framework for developing the future skills of seafarers. This paper addresses this gap by developing a framework for challenge-based education, emphasizing interdisciplinary knowledge and 21st-century skills such as critical thinking, problem solving, digital literacy, creativity, and communication. This framework allows for agile adjustments to meet the evolving and emerging needs of the maritime sector. The framework utilises genuine challenges of the maritime cluster that are defined in cooperation with maritime stakeholders and industry. The framework is customisable and it can be generalised to other fields of education.

KEYWORDS

Challenge Based Learning, Autonomous Maritime, Shipping, CDIO Standards: 1–3, 5–8

INTRODUCTION

Due to expected changes in the maritime industry caused by a wider introduction of Maritime Autonomous Surface Shipping (MASS) (Ghaderi, 2020), professionals in other sectors besides shipbuilding and operation will require an increasing understanding of how MASS operate. Cross-sectoral and inter-disciplinary understanding of the premises of autonomous shipping at large might also be beneficial for different kinds of professionals connected to MASS design, construction and operation. Higher degrees of autonomy requires bigger changes in many sectors connected to maritime transportation and face higher legal and business barriers (Tsvetkova et al., 2021). Future education needs to address these challenges as well. Namely, the understanding of legal foundations and current barriers for MASS is important both for further policy development (for example, how regulation should be changed) and for directing technological innovation (for example, how to prove the safety of certain technologies enabling MASS in order to reach regulatory compliance) (Bolbot et al., 2022). Also, given the uncertainty regarding the development of the maritime sector with a more abundant introduction of MASS, it is necessary to develop flexible teaching and learning frameworks, which would allow for agile adjustments and modifications according to emerging needs. In line with this, maritime experts expect a shift towards personalised training adapted to individual needs and an interdisciplinary approach integrating simulator-based and computer-based training, 3D simulations, and gamification (Nguyen, 2018).

The perspective of students, apprentices, seafarers at the beginning of early careers or in the maritime industry (cadets) and future maritime professionals have also been explored (Tsvetkova et al., 2024). With regard to seafarers, Bogusławski et al. (2022) conducted a worldwide survey to assess maritime cadets' attitudes towards autonomous shipping and its job market implications. The findings reveal that cadets feel current Maritime Education and Training curricula inadequately cover automation and autonomous systems. Despite this, cadets successfully identified essential skills for future shipping, such as remote situation awareness, IT proficiency, and multitasking across global assets. This indicates that cadets understand industry expectations and are optimistic about adapting to future challenges, including transitioning to shore-based roles if sea-going opportunities decline.

In an extensive literature review, Emad et al. (2022) evaluated the current state of knowledge on maritime education and training of future operators of autonomous and unmanned ships. Through comparing the maritime industry with other industries that have seen increased levels of automation such as mining and aviation, the authors suggested that the lack of an existing framework for training on MASS can be overcome through learning from these industries. In particular, the training of operators of automated equipment in these sectors has focused on developing cognitive skills, communicative abilities, analytical thinking, effective communication and taking efficient action. However, the authors concluded that there is a research gap in aligning seafarers' training to technological developments in MASS, as existing papers reiterate the need but fail to specify the type of training required or propose a framework for developing the future skills of seafarers.

This paper addresses this gap by developing a framework for challenge-based education, which emphasises interdisciplinary knowledge and 21st-century skills such as critical thinking, problem solving, digital literacy, creativity, and communication. This framework allows for agile adjustments to meet the evolving needs of the maritime sector, particularly in the context of MASS. The framework for Challenge Based Education (CBE) developed in this paper is based

on recognised educational needs in the MASS context (Bolbot et al., 2022). In education based on this framework, student teams seek creative solutions for current and future challenges in the field. The framework utilises genuine challenges of the maritime cluster that are defined in cooperation with working life representatives, that is, maritime stakeholders and industry. The framework is customisable and can also be generalised to other fields of education beyond the MASS context. The presented pedagogical framework and learning design for challenge based learning and other forms of learning design enable agile adjustments and modification of the content according to emerging needs.

The development of the CBE framework presented in this paper started in the AutoMare EduNet project funded by the Ministry of Education and Culture in Finland during 2021-2023. In AutoMare EduNet, a multidisciplinary collaboration network between universities was built to ensure the delivery of high-quality education to meet the emerging educational needs of MASS.

THE AUTOMARE FRAMEWORK FOR CHALLENGE BASED EDUCATION

The presented scalable AutoMare Challenge Based Education framework makes it possible for higher education institutions to dynamically offer up-to-date engagement between students and industry related to MASS solutions. Naturally, companies and industrial actors do not have sufficient incentives to take care of knowledge and information transfer on their own. Higher education institutions should make a long-term decision by selecting relevant faculties and disciplines to carry out ”living lab” activities, which integrate working with experimentation and research. In the AutoMare framework, the higher educational institutes are assumed to have existing industry collaboration which gets more focused and emphasised towards the field of autonomous maritime if the institute adopts the AutoMare framework. In principle, this requires that participating higher educational institutes:

1. have existing relevant expertise that can currently be connected to visions related to MASS (technology, business and operations, regulations, and so on). Most likely this is determined by each institute’s management themselves.
2. are willing to allocate teaching resources, especially in the MASS context, and also resources to coordinative work and industry collaboration.
3. also participate in R&D projects related to MASS, prepares new project proposals and participates in related networks.

Depending on the scale of teaching close to topics of MASS, the living lab can vary from being a part-time task of an individual teacher to being a stream of a larger university-industry collaboration team which interacts with companies in R&D projects.

Figure 1 summarises the AutoMare framework and its main sections. On the left side of the figure, the main phases of the framework related to the respective industry and students are shown. On the right side of the figure, the related activities of the living lab functions suggested for higher education institutes are shown. Each main phase is described in detail in separate sections.

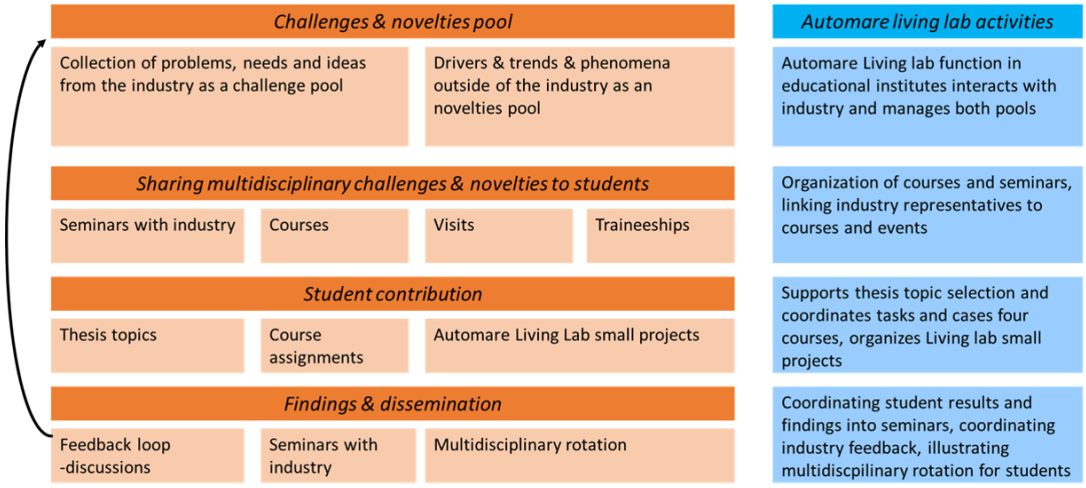


Figure 1. Automare Challenge Based Education Framework

Challenges and novelties pool

Each higher education institute interacts with different industries and stakeholders according to their own goals, resources, etc. At least in the case of Finland, the backbone for collaboration already exists. The question is whether the topic of MASS will be considered among the collaborations with feasible focus and expertise. The second question is whether, even if researchers engage in MASS research, the research results will also be transported to education.

In the AutoMare framework, the first phase covers activities that manage the collection of both challenges and novelties that could potentially reshape technologies, business and regulation related to the set context – MASS. In the framework, challenges refer to problems, needs or sleeping ideas within the core industry. Industry actors and start-ups especially often need to put their effort into immediate business goals and focus on generating concrete outcomes. However, they often run into broad and multidisciplinary challenges and questions that will have a longer-term effect with, for example, technology adoption. The AutoMare framework seeks to establish a sufficient dialogue between the parties in which higher education institutes could capture observations and thoughts on the challenges and convey them bit-by-bit to students and scholars to generate new knowledge and solutions. Challenges could include for example:

- improving sensor fusion techniques
- addressing poor connectivity issues in coastal areas
- business model scenarios related to, for example, remote operations or equipment maintenance
- ethics evaluation of different algorithmic decision-making outcomes
- investigating alternative supply chains relying on autonomous technologies and ecosystems
- scenarios that could be tested in a ship simulator environment

When developing radically new technology and surrounding sociotechnical regimes, the industry and educational sector need to take into account also other factors beyond challenges rising

from inside a certain set of actors. Both technological and industrial boundaries are always in motion even if there are rather broadly accepted visions of what autonomous maritime solutions might be in the future. It is likely that not all the elements needed are yet fully detected. Path dependency on how maritime technologies have evolved before or which are the currently active actors can lead to missing some potential coming from elsewhere. Therefore, in parallel with the pool of challenges, the AutoMare framework introduces a novelties pool. Novelties refer to drivers, trends and phenomena outside the current industry boundary that might shape the technological, operative and institutional development of MASS. Novelties include:

- positioning of remote work practices and culture in near future and impact on, for example, remote-operation technologies
- green transition demand impact for technologies and operations as well as investment financing
- possibility of superapps as tools for individuals managing their every day partly on their behalf
- collaborative robots joining in configuring new processes
- mass escape and career shifts from routine jobs

In practice, individuals or teams allocated to AutoMare living lab activities participate in collaboration with relevant companies and stakeholders and seek to pick up challenges and novelties from the field. Depending on the scale chosen, this collection can be passive observing or more actively pursued in dedicated events. Companies may choose whether they wish to be listed as the owner of the challenge or novelty, or if the topic should be listed in the pool anonymously.

Sharing challenges and novelties to the students

Industry collaboration and education have their own goals and they are often met separately. Therefore, in the AutoMare framework, the second phase of the higher education institutes' AutoMare living lab team members is to share challenges and novelties that get collected in the respective pools. Four basic methods for sharing are identified in the framework. The first one is the organisation of different seminars and events bringing together industry experts and students. Secondly, visiting lectures and thirdly, site visits to companies generate interaction in different courses. Fourthly, coordination with traineeships in MASS companies contributes to the accumulation of students' understanding of topics and opportunities, including the possibility of future employment.

During the third phase, the students contribute by familiarising themselves with the topic, discovering new research results and findings, and gradually generating new knowledge for themselves and the industry. Primary knowledge is obtained directly through tackling challenges, but also the importance of applied and generated tacit knowledge through interest and engagement with stakeholders must be recognised. In addition to project work, students can contribute by doing their theses on commission by stakeholders and have parts of the challenges or novelties solved as course assignments.

Students have diverse perspectives on how course material affects their motivation to attend classes. Some people live in remote regions, so access to online classes is useful. However, there is concern about the potential decrease in contacts between students and teachers during virtual sessions, which may hinder engagement, particularly owing to distractions (e.g., social

media). Students stress the value of on-site presence during activities like simulations and laboratory exercises.

Some courses that use project work, particularly in phase four of the presented framework, as a form of assessment allowing students to choose the technology they will use to execute the specified activity. With enough available time to experiment and test various technologies, students can fail and learn from their mistakes to improve their final project. Structured feedback mechanisms from peers, teachers and industry stakeholders can enhance the learning process and improve project outcomes. This assessment is relevant to CBE because students must investigate the novelty of technology or procedures that they have not before used.

EXPERIMENTS IN THE IMPLEMENTATION OF CHALLENGE BASED LEARNING

Challenge Based Learning can be implemented in different levels of abstractions depending on the challenge in question and on the learning goals of the study module incorporating the challenge. We define the key abstraction levels as three scopes for challenge based learning as follows.

1 "Course": in this scope, "design sprint" style innovation processes are applied in the student groups. The basic idea in the process is to generate a high number of raw ideas, and then collect feedback on them. Based on the feedback, the best raw ideas are selected for further development. In this kind of scoping the whole challenge-based learning approach can be utilised: stakeholders, for example companies, benefit from the students producing a high number and variety of ideas, then experts representing the stakeholders have the opportunity to consider the ideas, evaluate their realism and direct the forthcoming work of the student groups to suitable directions. Students will learn from the feedback and are able to utilise it in tackling the challenge but still the chance for fresh angles and solving strategies to appear remains strong.
2 "Topic/Development area": in this scope, the challenges would represent various development areas within autonomous maritime development, for example, various systems and their interoperability. Among the authors, there is recent experience in applying challenge based learning in this scope in innovation processes on topics like automation of container lashing and tanker berthing as a pre-step of remote pilotage. At this level of scoping it becomes evident to students that the operational environment in maritime always includes several actors with conflicting interests. Tackling the challenge requires understanding of all the actor's goals and the involved processes.
3 "Discipline": in this scope, the challenges include a predefined selection of different disciplines from which students are brought together for multidisciplinary perspectives to tackling a challenge. Investigating the different perspectives helps students grasp a broader sense of how to carry out multidisciplinary development for challenges in autonomous maritime. A selection of disciplines could cover, for example, different technical approaches (machine vision, data transfer, cyber security, automation algorithms, etc.) with business legal aspects. The development needs of the stakeholders might vary and situations could change during the challenge, potentially highlighting challenge based learning as a mechanism for participating higher education institutions to bring together experts in different fields to support the student teams, facilitating the building and growth of collaboration between various research groups and companies.

In the following, we discuss three experiments in challenge based learning from the higher education institutions represented by the authors, and consider how they align with the scopes defined above.

Challenge as a student project

As part of applying the CBE framework in Figure 1, and advancing autonomous ships' educational development at Aalto University, a small autonomous ship model was developed. The concept ship model constituted a miniature copy of an Icebreaker ship model. The model was developed in stages, where three Master students (Two summer workers and one thesis worker) addressed the general problem of designing, selecting and retrofitting the ship model with the necessary equipment as well as developing the relevant software code in Arduino and ROS2 software.

In each case, a set of problems for each student was specified based on the general and specific needs of the overall project plan for ship model design, similar to the one encountered in industry and academia. The project in each case had some specific aims, tasks and deadlines to be implemented by the students, and students were given freedom in adressing the tasks. Additionally, the position with a clear task description was advertised through the Aalto network, so that interested students could make the relevant application as per their interest.

The project execution was implemented under the close supervision of one Postdoc, one PhD student, Aalto Ice and Wave tank manager, and two Aalto professors. All of the students reported positive feedback to their engagement to the project and the Master thesis student (employed for 6 months contrary to 3 months and 1.5 months for the other two) received an offer from project industrial partners, where he continued applying the skills that he learnt during his Master thesis work. Additionally, the research conducted by the students had an academic impact, with students contributing to one journal and one conference paper, and with some research still ongoing, receiving good feedback from the industry.

Challenge as a course assignment

CBE can be integrated into both the activity design and assessment strategies within individual courses, providing students with opportunities for engagement and practical application. For instance, a challenge-based approach was incorporated into the assignment design of the course 'Smart and Sustainable Maritime Business' at the Laboratory of Industrial Management, Åbo Akademi University. In this main course assignment, students are tasked with selecting a problem or phenomenon within the maritime sector, analyzing it through the lens of wicked or potentially wicked problems. Autonomous shipping is provided as one of the phenomena that can be chosen by students for their course assignment.

The assignment begins with students defining the problem, focusing on potential risks and the interconnected aspects of sustainability involved. This initial step encourages them to consider the different dimensions of sustainability and the complexity of the issues related to autonomous shipping, such as legal considerations, impact on jobs in the maritime sector, and the potential environmental benefits of autonomous shipping. This way, the students are directed to identify the potential contentions and challenges that have emerged or will emerge as autonomous ships are increasingly introduced. Further, students investigate relevant digital and clean technologies that could play a role in addressing the challenges they have identified.

Finally, students attempt to provide solutions and recommendations for how the maritime sector needs to develop further to be able to benefit from and mitigate potential negative impacts of autonomous shipping. Given that the students come from various engineering backgrounds, such as computer science, energy technology, and marine biology, discussions within groups allow them to gain a multidisciplinary perspective on the problem.

In this particular case of a challenge-based learning type of assignment, the idea of having a challenge and novelty pool (see Figure 1) is utilised (top level), which is further shared with students in a course (second level), and is then analyzed by students as part of a course assignment (level 3). What still needs to be developed, is creating a feedback loop as implied at level 4. Although the final seminar in the 'Smart and Sustainable Maritime Business' course, where students present their assignments, brings together the students and some of the researchers at the Laboratory of Industrial Management, the involvement of industry representatives would be beneficial.

Innovation camp process with students as a research project facilitation method

Another type of approach has been tested by adding CBE activities into a research and development project rather than taking the education curriculum as the starting point. In this type of approach CBE activity is a tool for increasing a research project's co-operational and dissemination elements by integrating a challenge-based innovation process aboard. University of Turku (UTU) applied this approach in connection to autonomous maritime development in a project which general topic involved the advancement of intelligent fairways and remote pilotage. UTU had a pre-existing innovation process (Business Innovation Camp) based on design sprint which was applied for the project.

The innovation process supported the research project in two ways. Firstly, the part of UTU's business research was to explore the roadmap of international scaling for remote pilotage solutions. There an existing collaboration with the Singapore Maritime Institute was applied to relevant Singaporean organizations for pilotage aboard among Singaporean universities' researchers and students. This enabled in the process eye-opening discussions reflecting the contrasts between two very different operational environments for pilotage between Finland and Singapore. Secondly, the innovation process aim was to introduce a further detailed real-life challenge from the roadmap from today's pilotage operations on the way to remote operations. The chosen challenge was considering possible solutions for tanker berthing if automation or remote operations would be added. The process was supported by maritime educators from Novia University of Applied Sciences and a few technology supplier representatives.

The innovation camp process is a different research-originated approach which enables the students to get involved in really state-of-art discussions from the industry related to different needs and ideas. It doesn't require attributes related to traditional educational courses in the curriculum, but it can introduce opportunities for pioneering dialogues and interaction possibilities for selected students. Therefore it's most beneficial for students who for example have almost completed their studies and are planning for their thesis work or such. However, carrying out the process requires considerably more tailored planning and isn't easy to replicate. But as part of the curriculum for selected students such a CBE framework can offer very detailed, impactful and network-expansive experience as one of the final milestones in any degree.

CONCLUSION

The role of Challenge-Based Education (CBE) extends far beyond a single course; it is a continuous, transformative process that shapes the framework for interaction and drives a cultural revolution in education delivery. In the AutoMare framework, this transformation is reinforced through a feedback loop that shares findings and results. Organized events, such as industry seminars, provide platforms where students present their contributions to stakeholders, creating opportunities to refine and generate new challenges. A key feature of this loop is multidisciplinary rotation, where students are briefly rotated between different disciplines and stakeholders, such as technology developers, operators, and authorities, to broaden their perspectives. This approach not only enriches the learning experience but also fosters continuous innovation and collaboration across fields.

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ENGINEERING CLEAN WATER SOLUTIONS: A CHEMICAL ENGINEERING OUTREACH ACTIVITY FOR SECONDARY STUDENTS

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ABSTRACT

University outreach activities can inspire high school students to pursue STEM pathways. A new workshop, Engineering Clean Water Solutions, was developed at Monash to showcase chemical engineering principles through a practical design workshop, which situated students in realistic engineering roles (CDIO Standard 1) and engaged them in team-based development and testing of a water treatment process (Standard 5, Standard 8) that balanced efficiency, cost, and effectiveness. They also experienced analogous industrial practices at the Monash Membrane Pilot Plant. Student feedback highlighted the workshop's interactivity and industry relevance, demonstrating the value of aligning outreach activities with the CDIO framework. Importantly, this implementation of CDIO also illustrates how the Framework can be used as a pedagogical tool and also as part of the broader strategy of an institute to support goals such as student recruitment, offering an example of curriculum agility in action.

KEYWORDS

Chemical Engineering, STEM Outreach, Experiential Learning, Authenticity, Standards 1, 5, 8.

INTRODUCTION

University outreach activities are powerful pedagogical tools for fostering interest in STEM disciplines among high school students. Research has consistently shown that hands-on, immersive experiences significantly enhance students' motivation and understanding of STEM concepts, bridging the gap between abstract classroom learning and real-world applications (Maltese & Tai, 2011; Sadler et al., 2012). Outreach programs that align with frameworks such as the Conceive-Design-Implement-Operate (CDIO) framework (Crawley et al., 2014) provide students with authentic engineering experiences by situating them in real-world contexts (Standard 1: Context).

This is evident in Australia, where several programs have demonstrated significant impact. For example, the University of Newcastle Science and Engineering Challenge (SEC) engages high school students in STEM through collaborative, practical activities. It has demonstrated a measurable influence on tertiary STEM enrolments, with a decadal study showing that nearly one-third of participants pursuing STEM degrees as a result of this outreach experience (Reed et al., 2021). Similarly, a study of STEM outreach programs across Australian universities has highlighted their vital role in reversing declining STEM enrolments by aligning activities with the interests and aspirations of students, while also addressing workforce needs (Sadler et al., 2018). The effectiveness of such practical STEM outreach activities is also recognised by industry. For instance, the BAE Systems ‘Beacon’ program provides Year 4–6 students with access to modern technologies and real-world challenges, aiming to boost awareness and improve workforce development into the future (Pickham, 2022).

Building on the literature evidence of the success of such programs, Monash University has developed its own initiatives to inspire the next generation of engineers. One example is the annual John Monash Science School (JMSS) Immersion Day, which showcases Monash Engineering’s facilities and provides an immersive, hands-on experience. The goal is to give students a real insight into what it’s like to be a Monash Engineering student and allow them to interact with engineering academics and current students. This program supports CDIO Standard 5: Design-Implement Experiences by engaging students in collaborative, practical activities that emulate the work of engineers. The program spans a full day and includes two workshop sessions where students can choose activities that explore different engineering disciplines. This tailored approach enables students to align their interests with diverse opportunities in engineering.

In the past, Chemical Engineering outreach workshops at Monash have focused on chemistry-based projects, such as making bouncy balls, and physics-based experiments, like exploring fluidised beds. These activities effectively demonstrate foundational principles crucial for chemical engineering—such as polymerisation reactions, material properties, and fluid dynamics—which are essential for understanding the behaviour of materials and systems. However, such activities present only isolated phenomena and lack the integration and complexity inherent to chemical engineering. The essence of chemical engineering lies in applying these scientific principles to design and optimise processes that transform low-value feedstocks into high-value products, balancing efficiency, sustainability, and scalability. This broader, systems-oriented perspective, involving process design, scale-up, and economic considerations, distinguishes chemical engineering from its foundational sciences (University of British Colombia, 2025). In parallel, the increasing focus on curriculum agility in engineering education encourages the development of learning experiences—both within and beyond formal curricula—that can adapt to emerging needs and better engage future cohorts (Brink et al., 2020).

To better reflect the systems-oriented nature of chemical engineering, we developed a new activity for the 2024 John Monash Science School (JMSS) Immersion Day that engages students in process design and iterative problem-solving. This paper describes the activity, evaluates its impact, explores its alignment with the CDIO framework, and as proposes future improvements.

ENGINEERING CLEAN WATER SOLUTIONS – ACTIVITY DESCRIPTION

The Engineering Clean Water Solutions workshop is a 90-minute activity designed to engage secondary school students with the principles and practices of chemical engineering and inspire them to pursue their interests in STEM. The workshop highlights the critical role of chemical engineers in designing and optimising processes to convert low value feedstock to higher value products.

The workshop is predominantly practical: it begins with a short introduction explaining that industrial water treatment involves multiple steps to remove turbidity (cloudiness) – a key water quality parameter in industrial processes. Students then work in teams of 3–4 to design and optimise a water treatment process of their own by using a combination of physical and chemical treatment methods. Each team is given a sample of murky water and some simple benchtop equipment to enable them to treat their water by gravity settling, media filtration, membrane filtration, and chemical coagulation. They are asked to combine these treatment steps in any order and frequency to develop a treatment process that achieves the clearest water possible while balancing competing objectives such as efficiency and cost. Teams are encouraged to test the turbidity of their cleaned water as they go, enabling them and refine their processes and highlighting the iterative nature of engineering design.

Turbidity was chosen as the quality metric for this challenge because it is a key parameter in potable water standards and provides an accessible, visually satisfying measure of success. At the end of the session, the cohort comes back together and the lowest turbidity achieved by each Team is presented. The discussion focusses on the number and cost of the steps required to achieve the best results to highlight the multi-objective nature of industrial process design.

To contextualise their learning, the workshop also includes a guided visit to the Monash Student Pilot Plant, an industry-scale water treatment facility. Students are told more about industrial water treatment and observe the operation of the membrane filtration system. They are given an opportunity to collect and analyse the turbidity of water samples from the pilot plant, and compare their experimental results with the performance of the industrial system. This provides insights into scale-up challenges and the optimisation of design processes in professional engineering practice.

Through this workshop, students gain a practical understanding of chemical engineering principles, particularly the integration of physical and chemical methods to address real-world challenges. The activity fosters key skills such as teamwork, problem-solving, and iterative design, while explicitly connecting small-scale experiments with industrial applications. By providing a hands-on experience framed within a real-world context, the workshop offered students valuable insights into the profession of chemical engineering and its pivotal role in improving water quality and access on a global scale.

CDIO ALIGNMENT

The design challenge activity aligns closely with several CDIO standards, providing students with an authentic learning experience presented in the context of a real-world engineering challenge. It addresses:

- **Standard 1: Context** by situating students in the role of chemical engineers, designing water treatment systems that mirror industrial practices
- **Standard 5: Design-Implement Experiences** was exemplified as students progressed through the design and testing of their solutions, iterating to improve their results.
- **Standard 8: Active Learning** through its hands-on approach to exploring water treatment principles

By embedding these standards, the activity offers an authentic, engaging and practical introduction to chemical engineering to reinforce students interests and inspire them to pursue a STEM degree.

While the CDIO framework is often applied within formal curricular structures, this outreach activity demonstrates its utility in broader educational and institutional contexts. In particular, it aligns with the “Conceive” and “Design” stages not only through project-based learning, but as part of a strategic recruitment initiative. By offering prospective students a realistic and engaging engineering experience, the activity reflects curriculum agility and highlights how CDIO principles can support both student preparation and institutional responsiveness to future educational demands. In particular, our activity development reflects several of the relevant curriculum agility principles identified by (Brink et al., 2020). In particular, it reflects a proactive approach to curriculum development, is responsive to stakeholder needs, and aligns with institutional strategy by creating a forward-looking activity that engages and involves prospective students.

STUDENT FEEDBACK

Student feedback was collected by JMSS educators and comments were provided in deidentified form to Monash administrators of the Immersion Day. Students generally found the Engineering Clean Water Solutions activity engaging and informative, highlighting its hands-on nature and the opportunity to take initiative in solving the water treatment challenge.

Several students appreciated the interactivity of the workshop, noting that it offered a break from traditional lecture-style learning. One student remarked, *“It was interactive and engaging so we weren’t listening to a lecture the entire time and a lot of it was taking our own initiative to solve the problem.”* Others praised the clarity and simplicity of the explanations about chemical and process engineering, which made the concepts accessible and relatable. Students also enjoyed the challenge of creating the cleanest water and comparing their results, with one student commenting, *“It was fun, the little competition in trying to make the ‘cleanest’ water.”* Additionally, the hands-on experiment was commended for providing practical insights into water treatment methods and allowing students to compare the effectiveness of different approaches.

However, while most appreciated the activity's design, some suggested enhancements to the fairness and clarity of the task. For instance, one student suggested including a better explanation of the relative costs of the different treatment methods. Another proposed using a variety of samples, such as laundry water or river water, to simulate more realistic scenarios.

FUTURE IMPROVEMENTS

Based on feedback from the students and discussions with the demonstrators, the student engagement and experience will be enhanced in future iterations of the workshop by: including a wider variety and choice of water samples, improving the results submission process, and enhancing the workshop conclusions.

Providing students with a variety of sample to test, such as river water, laundry wastewater, and stormwater, will enhance authenticity and engagement. This adjustment will highlight the need for chemical and process engineers to tailor processes to specific feedstocks, even when the desired product, like clean water, remains the same. By encountering diverse scenarios, students will gain a deeper understanding of how unit operations are adapted to design efficient, sustainable, and scalable solutions. This improvement aligns with CDIO Standard 1: Context, as it situates the activity in realistic engineering challenges. It also gives students more autonomy and ownership over the workshop activities, enabling them to pursue their interests rather than being restricted to a particular scenario.

The workshop's conclusion will be restructured to provide stronger closure and reinforce key messages about water treatment and chemical engineering. By linking back to the introductory discussion on the iterative, multi-objective nature of chemical engineering process design, students will see how their hands-on activities reflect the work of chemical engineers in integrating physics and chemistry principles into practical designs. This will help clarify the broader role of chemical engineers in addressing global challenges while meeting quality, sustainability, and cost objectives, supporting CDIO Standard 7: Integrated Learning Experiences by tying practical activities to theoretical concepts.

In this first offering of the workshop, we relied on a QR code link to enable students to submit their results for the competition and workshop conclusion. However, most students did not have access to a device with which to do so as it is standard procedure for secondary students to leave devices in their bags during class. Therefore, to improve the flow of the activity, the results submission process will be updated. Future workshops will include shared devices at workstations for direct data entry into a central system and students will be supported by facilitators to upload results. These changes will reduce logistical barriers and maintain the competitive element of the workshop, aligning with CDIO Standard 8: Active Learning by ensuring students remain focused and engaged in iterative problem-solving.

POTENTIAL RESEARCH DIRECTIONS

Potential future research directions could explore ways to further evaluate and enhance the workshop's impact and effectiveness. Developing a standard survey for students to complete after participating in the workshop each year could provide valuable, ongoing insights into how they engage with iterative design and integrated problem-solving. Longitudinal studies might track participants' academic and career pathways to assess how experiential learning activities influence STEM choices. A longitudinal study could track participants' academic and career pathways to evaluate the workshop's influence on STEM choices. Expanding the workshop to include professional development for secondary teachers could empower educators to better integrate STEM concepts into their curricula and provide more informed guidance to their students. Additionally, research could examine the effectiveness of CDIO integration, such as how students grasp iterative design and teamwork. These directions could help to further refine the workshop while expanding its educational and societal contributions.

CONCLUSION

The Engineering Clean Water Solutions workshop shows how well-designed outreach activities aligned with the CDIO framework can inspire high school students. Students engaged in designing water treatment processes using physical and chemical methods, building practical skills such as teamwork and iterative design while connecting their lab work to real-world engineering solutions through their experience with running the Monash Membrane Pilot Plant visit. The workshop reflected several CDIO standards, including Standard 1: Context, by situating students in realistic engineering challenges, Standard 5: Design-Implement Experiences, through iterative process design, and Standard 8: Active Learning, by engaging students in hands-on, team-based problem-solving.

Student feedback praised the hands-on, interactive approach and the clear explanation of engineering concepts, though areas for improvement were identified. Suggestions include incorporating diverse water samples to enhance authenticity and refining the session's conclusion to reinforce key learning outcomes. Future iterations will implement the proposed improvements, enhancing the workshop's educational impact while continuing to inspire the next generation of chemical engineers to tackle real-world challenges with confidence and creativity. Potential research directions include developing a standardised survey to evaluate student experiences annually and exploring the workshop's impact on fostering systems thinking and long-term interest in STEM pathways, providing valuable insights for refining outreach strategies.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Rukhsar Kaur and Johnny Nguyen, the Monash undergraduate students who acted as laboratory demonstrators during the Workshop. Funding for this project was provided by Monash University Faculty of Engineering.

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GENERATIVE AI USE STATEMENT

In this manuscript, GenAI was used to refine and organise human inputs, descriptions and content, including summarising, language editing, and connecting concepts to literature and pedagogy.

BIOGRAPHICAL INFORMATION

Poh Xian Tay completed his bachelor's degree in Chemical Engineering at Monash University in 2021 and began his career as a production engineer in the fine chemicals industry. He collaborated with R&D chemists in scaling up lab-scale reactions to industrial production. During his role, he was involved in the design, modification, and optimisation of engineering equipment to meet various production goals. Currently, Poh is a Technical Officer and lab manager at the Faculty of Engineering at Monash University, focusing on supporting research students and teams with their projects, prototype and analytical testing, and equipment training, all while ensuring a safe working environment.

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ENHANCING LEARNING OUTCOMES BY USING SOME ELECTRONIC TECHNOLOGIES

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ABSTRACT

Since 2018, Mongolian National Defense University (MNDU) has been implementing CDIO standards and methodologies in its teaching activities. To enhance student knowledge and skills, MNDU has integrated various e-learning technologies into its curriculum. This study investigates the impact of Microsoft OneNote on student learning outcomes by analyzing its effects on information retention, note-taking efficiency, and student engagement. The study involved first- to fourth-year students in the Department of Engineering at MNDU, comparing traditional face-to-face lectures with the integration of Microsoft OneNote.

KEYWORDS

Flipped classroom, digital note-taking, Microsoft OneNote, student engagement, academic performance, Standards 5, 7, 8, 9

INTRODUCTION

The rapid digital transformation in education has necessitated an increased reliance on e-learning tools to enhance student engagement and optimize learning efficiency. Engineering education, in particular, benefits significantly from digital note-taking applications, which enable students to systematically structure information, integrate multimedia resources for enhanced comprehension, and foster collaborative learning. However, existing challenges such as information overload, inefficient self-regulation, and difficulties in adapting to digital platforms continue to hinder effective utilization.

This study critically examines the role of Microsoft OneNote as a digital note-taking tool in engineering education, assessing its impact on students' academic performance, cognitive retention, and organizational skills. Unlike other note-taking applications, OneNote offers advanced features, including hierarchical organization, seamless cloud synchronization, and collaborative functionalities. By addressing these challenges, this research seeks to provide empirical insights into how OneNote facilitates skill development and enhances academic success within an engineering education context.

RELATED WORKS

Previous research on digital note-taking in education highlights its potential benefits, including enhanced memory retention, improved organizational skills, and increased student engagement. Wong et al. (2022) explored the integration of Microsoft OneNote in university classrooms, finding that it facilitated collaborative learning and improved information structuring. Michaelsen (2020) emphasized the role of digital tools in modern education, arguing that platforms like OneNote enable a seamless blend of traditional and digital note-taking. Sekarasih and Yani (2016) investigated the effectiveness of OneNote in language learning, revealing significant improvements in student participation and comprehension.

While these studies establish the advantages of digital note-taking, few have explored its specific impact on engineering education. This study builds upon prior work by assessing how Microsoft OneNote influences students' ability to process and retain complex technical information.

Aim of the research work

To assess the impact of Microsoft OneNote on student learning outcomes in engineering education.

Research objectives

- To analyze the time students spend using Microsoft OneNote for academic purposes.
- To conduct a survey measuring the effectiveness of Microsoft OneNote in improving note-taking skills.
- To evaluate the skills most enhanced by using Microsoft OneNote, including information organization, problem-solving, and collaboration.

In this article, we share our experiences using some of the software and electronic technologies in our lessons.

METHODOLOGY

This study employed a mixed-methods approach, combining quantitative surveys and qualitative observations. A total of 150 students from the Department of Engineering participated in the research. The methodology included:

- **Survey Design:** A structured questionnaire was developed to assess students' use of OneNote, their engagement levels, and perceived benefits.
- **Data Collection:** Surveys were distributed online, and focus group discussions were conducted to gather qualitative insights.
- **Data Analysis:** Descriptive statistics were used to quantify student responses, while thematic analysis was applied to interpret qualitative feedback.

FINDINGS AND ANALYSIS

While the rapid development of technology has been a positive aspect, the ability of young people to use technology is increasing, but due to the lack of self-management skills of students, they are increasingly getting lost in the online environment and spending time ineffectively, as is clear from the results of this survey question. For example: 37.9 % of students spend 3-4 hours ineffectively on the Internet.

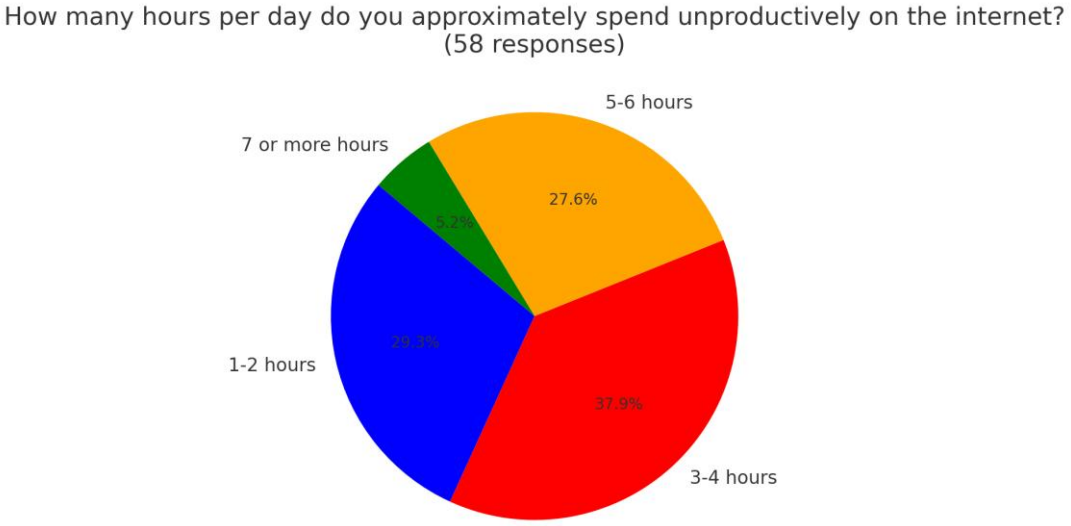


Figure 1. Survey of student internet usage

Figure 1. % of survey participants said they spend 1-2 hours effectively on the internet.



Figure 2. Survey of students' internet usage

We, the researchers, have studied the results of the above study and have come to the following solutions, examining how to resolve them positively. These include :
It is believed that it is a top priority for students and listeners of the National University of Economics, as well as students of other universities and colleges, to learn the skills of taking notes in both manual and electronic form, which will significantly reduce the time spent ineffectively on the Internet. Here are some brief methods for taking notes online:

There are 4 main ways to take notes by hand.

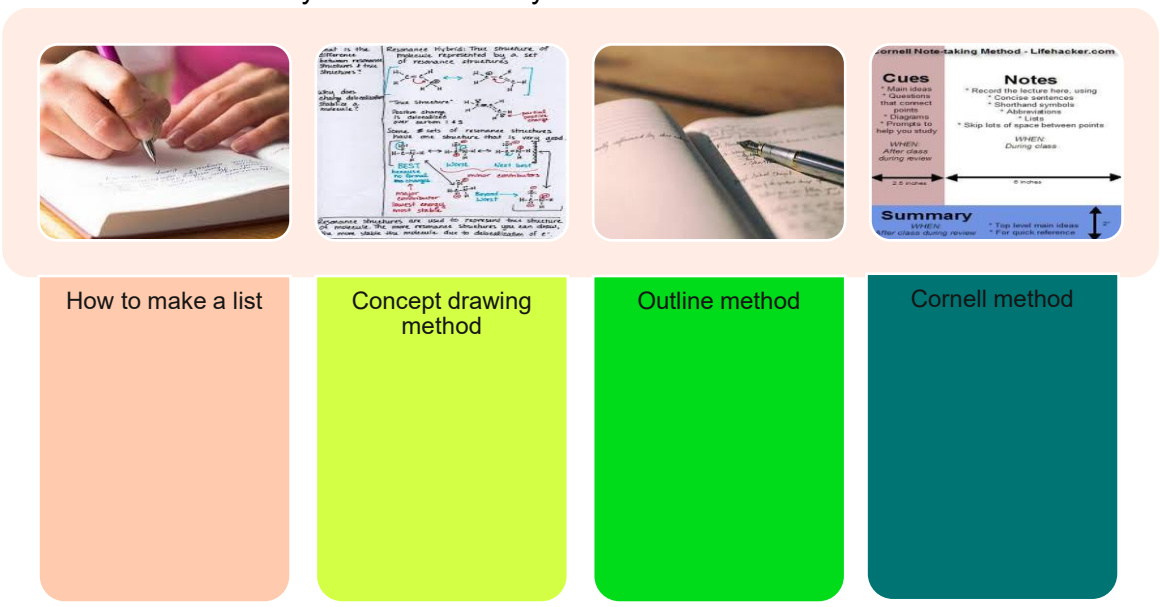


Figure 3. Manual note-taking methods

Let's briefly introduce some online note-taking programs. These include:

- OneNote
- Evernote
- Keep
- Simplenote

- Notion
- Diego
- Zoho Notebook
- WizNote
- WorkFlowy
- There are apps like Nimbus Note.

Of these methods, the following methods were used in training and the results were analyzed.

Microsoft OneNote allows you to create an unlimited number of notebooks, which can be divided into pages and sections. All this creates a multi-level data structure and helps you organize information intelligently. Handwriting and drawing functions are supported, and you can insert web videos and screenshots, record audio notes, and add Word documents, Excel spreadsheets, and PowerPoint presentations as file attachments or virtual prints (images). The most recent important entries can be tagged for quick access later, and notebooks with confidential information can be password-protected. OneNote has advanced search tools and allows you to share notes with colleagues, friends, and family. Without a Microsoft 365 subscription, users only get the basic features of OneNote and 5GB of cloud storage. The free option does not support notebook or handwriting recognition and reduces the ability to solve mathematical equations, but OneNote is a great option for taking notes and organizing personal information.

User surveys also show that the method can be beneficial when used for meetings, and seminars, taking class notes, and developing thesis papers.

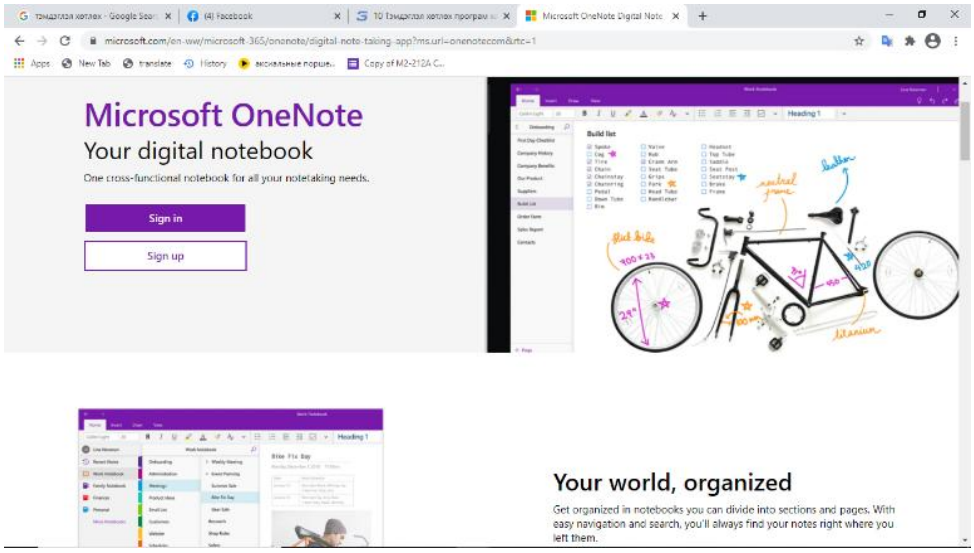


Figure 4. Appearance of the Microsoft OneNote electronic note-taking program

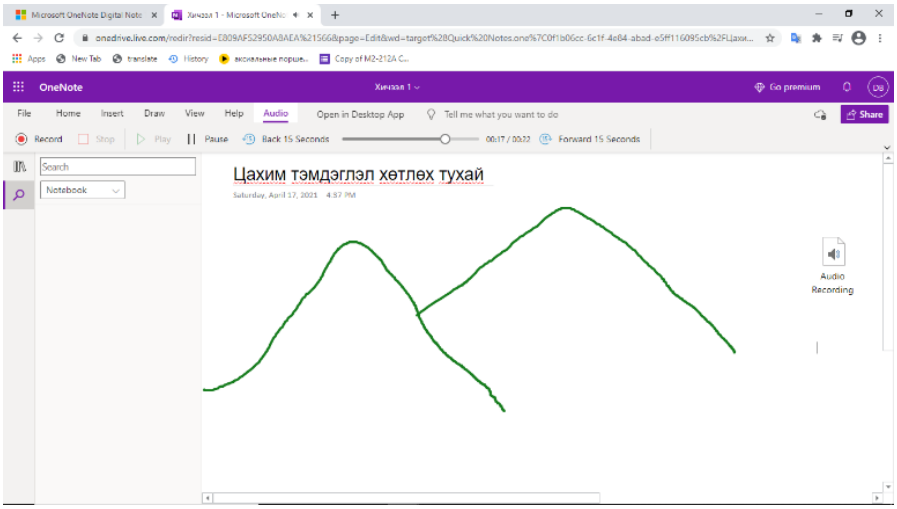


Figure 5. The note-taking area in the Microsoft OneNote electronic note-taking program

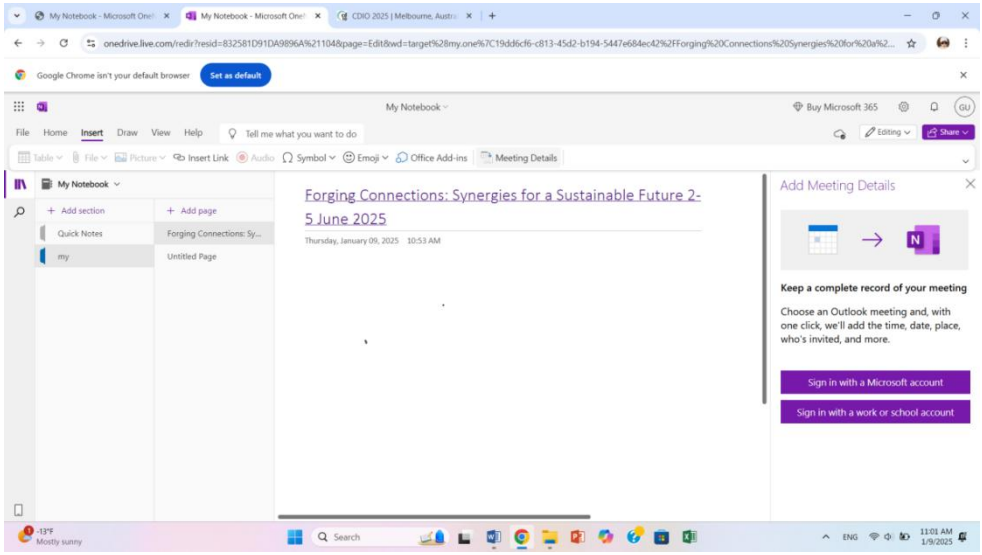


Figure 6. Microsoft OneNote link insertion and meeting time entry field

Also, based on the interests of students and the demands of employers, there is a legitimate need for teachers and students to widely use drawing and calculation computer programs and mobile applications, which is believed to be another way to increase learning outcomes and positively impact the academic success of students and listeners.

In line with the current situation, by changing the way students take notes, and combining handwritten notes with electronic technology, students' computer skills have improved, and they can summarize a wide range of knowledge and draw conclusions in a short time.

Microsoft OneNote from 1st to 4th year students of the Engineering Department of the National University of Economics and Business Administration and conclusions were drawn from the results. 100% of the students of the department participated in the survey and freely expressed their opinions.

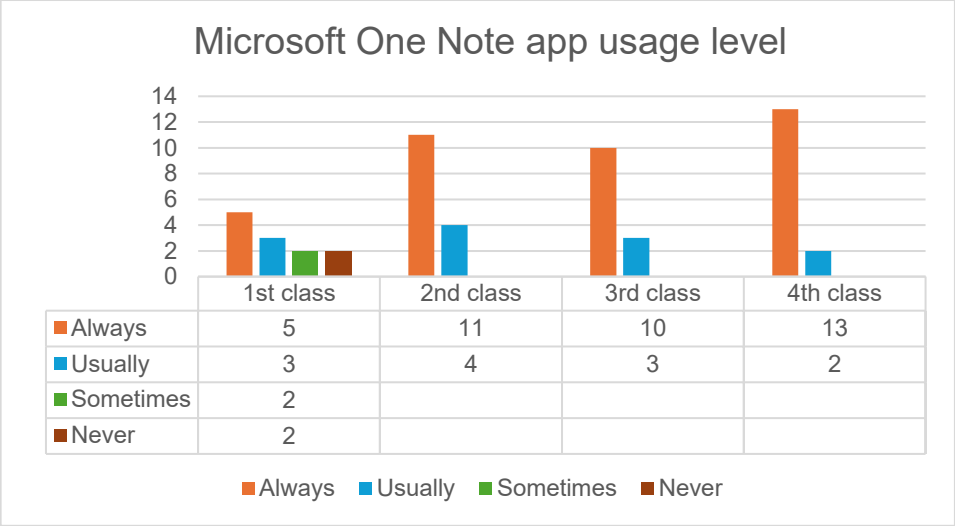


Figure 7. Microsoft OneNote usage rate

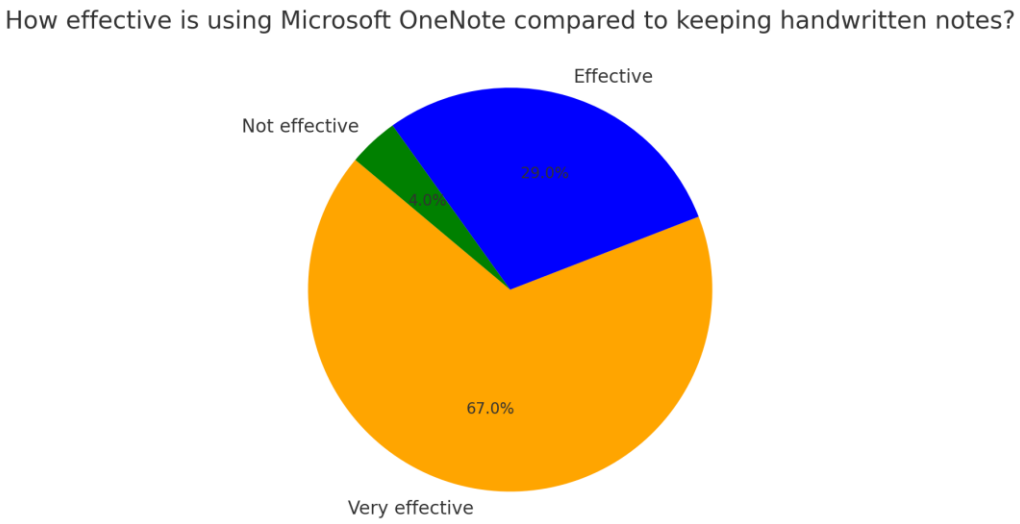


Figure 8. Satisfaction of Microsoft OneNote users

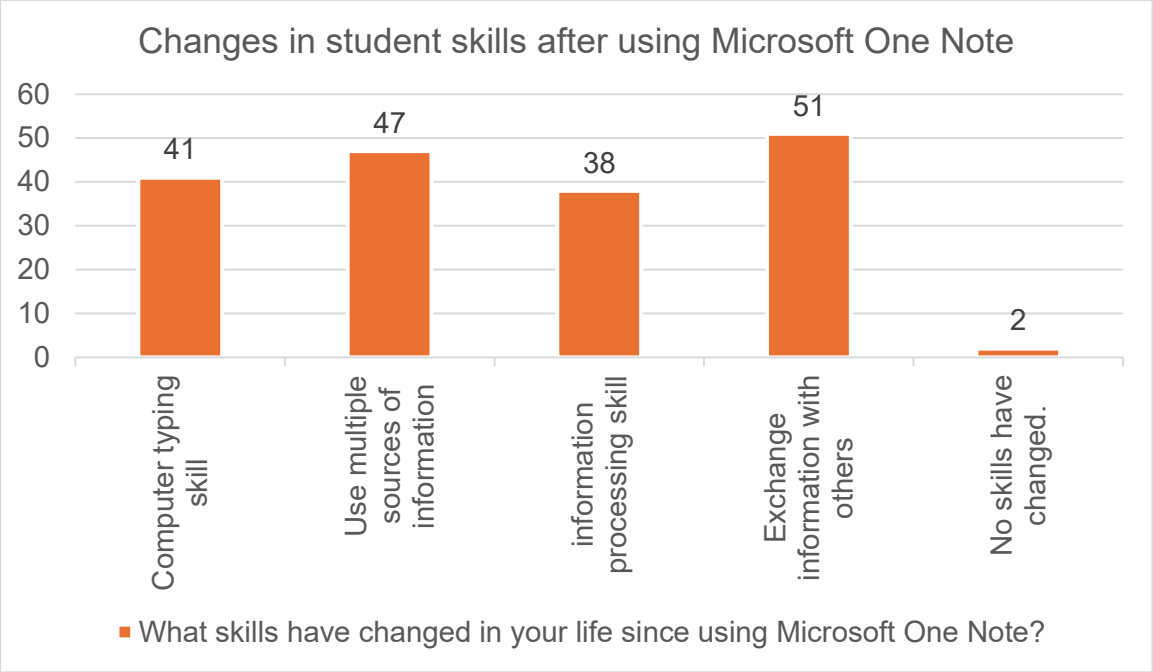


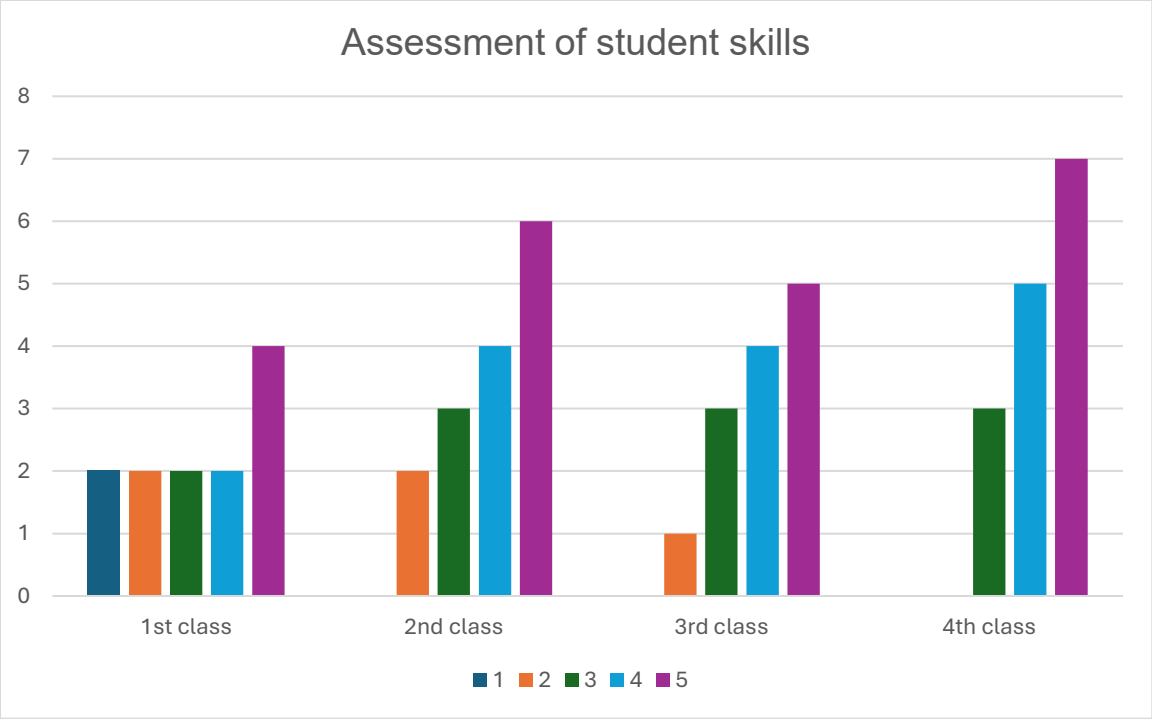
Figure 9. Changes in Microsoft OneNote user skills

Teachers who used Microsoft OneNote in their lessons used an assessment rubric to determine the skills students in the department learned through the program.

Rubric assessment of skills learned using Microsoft OneNote

Criteria	1-Not used at all	2-Interested	3-Sometimes used	4-Use yourself	5-Teaching others	Rating percentage
Ability to use Microsoft OneNote	Didn't learn the program at all.	Write notes on the program.	Write notes and draw pictures in the app.	Write notes, draw pictures, download files, and process information from multiple sources.	You can use all the program commands yourself and teach them to others.	0-100 %
Total points	0	20	50	80	100	100 %

When all students of the Engineering Department of the Security Institute of the National University of Mongolia were given a specific task and their skills in using Microsoft OneNote were assessed using a rubric, the following picture emerged: 50-70 percent of students learned to use it themselves and were able to teach it to others.



RESULTS AND DISCUSSION

Student Time Allocation in Digital Environments. Survey results indicate that while students spend significant time online, a notable portion is used inefficiently. Approximately 37.9% of students reported spending 3-4 hours online without clear academic objectives. The integration of OneNote reduced this inefficiency by promoting structured study sessions.

Impact of OneNote on Note-Taking Skills. A comparative analysis of student performance before and after implementing OneNote revealed improvements in note organization, accessibility, and retention. Figures 1 and 2 illustrate the increased adoption of structured note-taking practices among students.

Student Perception and Satisfaction. Survey responses indicated high satisfaction levels among students using OneNote. Approximately 80% reported that OneNote improved their ability to consolidate lecture materials, while 65% found it enhanced their problem-solving skills.

Skill Development Through Digital Note-Taking. A rubric-based assessment demonstrated that 70% of students reached proficiency levels where they could independently use OneNote for academic purposes, and 30% progressed to teaching others. This indicates that digital note-taking fosters self-directed learning and peer collaboration.

CONCLUSION

This study confirms that integrating Microsoft OneNote in engineering education significantly enhances student learning outcomes. Key findings include improved note organization, increased academic engagement, and the development of digital literacy skills. However, proper implementation by educators remains crucial to maximizing the benefits of digital tools. Future research should explore long-term impacts and investigate the integration of other digital platforms in engineering education.

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BIOGRAPHICAL INFORMATION

Darkhantsetseg Batsumber is working as an educator at Mongolian National Defense University's Institute of Safety's Department of Engineering. Graduated with bachelor's and master's degrees in Mechanical engineer of road transport and construction machinery, and currently a PhD student at the Mongolian University of Science and Technology. Continuously doing research work on the topic of wear of excavator blades and teeth. Advanced CDIO standards and methods master teacher.

Temuujin Altansukh has been working as a teacher since September 2023 at Mongolian National Defense University's Institute of Safety's Department of Engineering. Graduated with a bachelor's degree "Mechanical Engineering" at MNDU. He studied UNESCO's Usage of artificial intelligence in high school and was certified as a master teacher at Mongolian University of Science and Technology. Now he is studying for a master's degree in "Cyber Security" at MNDU.

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CLOSING THE GAP IN ENGINEERING EDUCATION: A POSITIVE PSYCHOLOGY APPROACH TO CDIO

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ABSTRACT

University engineering education aims to equip students with the technical and employability skills sought by employers. This often requires resilience, teamwork, and adaptability to succeed in collaborative, real-world projects. The CDIO (Conceive-Design-Implement-Operate) framework provides a solid foundation for fostering these competencies. However, student well-being and engagement remain underexplored and pedagogically underdeveloped within engineering curricula. This paper introduces the "Together Empowered" project, a Royal Academy of Engineering-funded initiative addressing equality, diversity, and inclusion (EDI) challenges in engineering education through Positive Psychology Interventions (PPIs). The project integrates workshops, mentorship, and real-world problem-solving to enhance the psychological and professional competencies of students from diverse backgrounds. A five-phase implementation process was adopted, including EDI awareness training, industry collaboration, structured positive psychology activities, and evaluations using qualitative and quantitative methods. Findings demonstrated significant improvements in student well-being across the PERMA dimensions (positive emotions, engagement, relationships, meaning, and accomplishment), with a 30% increase in positive emotions and substantial gains in engagement and relationships between the start and end of the module. Students also reported improved communication, problem-solving, and teamwork skills. Additionally, the project fostered a stronger sense of belonging and cultural sensitivity, supporting retention and progression within engineering degree programs. The integration of PPIs and EDI principles within the CDIO framework not only enhanced academic outcomes but also bridged the gap between academia and industry. The paper concludes by discussing the broader implications of these findings for creating inclusive, supportive learning environments that prepare students to contribute meaningfully to society and achieve sustainable career success in engineering.

KEYWORDS

Positive Psychology, PERMA Model, CDIO Framework, Diversity and Inclusion, Engineering Education, Standards: 2-4, 7-8, 10

INTRODUCTION

Engineering education has evolved significantly in recent years to meet the demands of a rapidly changing world. Traditional engineering curricula have primarily focused on technical knowledge and skills, often overlooking the importance of personal and interpersonal competencies (Crawley et al., 2007). However, the increasing complexity of global challenges requires a new generation of engineers who are not only technically proficient but also equipped with the emotional resilience, teamwork capabilities, and cultural awareness necessary to navigate these challenges (Baumeister & Leary, 1995).

The CDIO (Conceive-Design-Implement-Operate) framework addresses this need by emphasising the development of holistic competencies through active learning, problem-solving, and teamwork. Yet, many engineering programs that adopt this framework still lack a specific focus on student well-being and inclusivity (Magnell et al., 2022). Research shows that student well-being is a critical factor influencing academic performance, engagement, and long-term career success (Seligman, 2011). The integration of Positive Psychology Interventions (PPIs) into the CDIO framework can significantly enhance the educational experience by fostering emotional resilience and promoting positive relationships among students (Butler & Kern, 2016).

The "Together Empowered" project was launched to address this gap by embedding PPIs and Equality, Diversity, and Inclusion (EDI) principles into engineering education. This initiative aims to reduce attainment gaps among minoritised groups, such as Black, Asian, and Minority Ethnic (BAME) students, women, and LGBTQ+ students, by promoting a sense of belonging and cultural sensitivity within engineering programs (Berry, 2005). Additionally, the project seeks to strengthen connections between academia and industry by involving students in real-world projects that address pressing global issues, such as climate change (Jones et al., 2017). With the aims in long term to improve graduate employment outcomes for diverse students, as historically and currently gender, ethnicity, and social-background all impact engineering students' employment prospects (Fanusie et al, 2024) which is disappointing, as diverse teams improve the economic growth of enterprise (Martins, 2020). By collaborating with industry representatives and working in diverse teams the students gain practical exposure to professional practices while developing innovative inclusive solutions to societal challenges (Rybnicek & Königsgruber, 2019).

Martin Seligman's PERMA (positive emotions, engagement, relationships, meaning, and accomplishment) model provides a structured framework for enhancing student well-being within this project. The model focuses on five key elements that contribute to human flourishing: Positive Emotions, Engagement, Relationships, Meaning, and Accomplishments (Seligman, 2011). By incorporating these elements into the CDIO framework, students can develop the psychological resources needed to thrive both academically and professionally. The PERMA model also aligns with the goals of the CDIO initiative by promoting active engagement, meaningful relationships, and a sense of accomplishment (Seligman et al., 2005).

Research conducted by Plewa et al. (2013) highlights the importance of university-industry collaborations in fostering innovation and preparing students for the workforce. These collaborations provide students with valuable insights into industry practices, helping them develop technical and soft skills such as communication, teamwork, and problem-solving. The "Together Empowered" project leverages these collaborations to create a supportive learning environment that promotes cultural sensitivity and inclusivity in professional settings (Rubio et

al., 2018). Industry mentors are crucial in guiding students through real-world challenges, offering feedback and fostering a culture of continuous improvement.

The need to enhance student well-being within educational settings has been widely recognised in positive psychology literature. Baumeister and Leary (1995) argue that the need to belong is a fundamental human motivation that significantly impacts psychological well-being. Similarly, research on acculturation and cultural adaptation by Berry (2005) and Zhou et al. (2008) emphasises the importance of facilitating inclusive learning and teaching environments (Beddoes et al, 2018) that support diverse student populations. By fostering a sense of belonging and promoting positive psychological resources and psychologically safe learning spaces, educational institutions can help students overcome cultural barriers and increase all student academic engagement with one another and personally to be academically successful.

This paper aims to explore how the integration of PPIs and EDI principles within the CDIO framework can address challenges related to student well-being, engagement, and cultural adaptation. By presenting the findings of the "Together Empowered" project, this paper seeks to contribute to the ongoing discourse on improving engineering education through holistic and inclusive approaches. The inclusion of diverse perspectives and the focus on well-being not only prepares students for successful careers but also equips them with the skills needed to contribute meaningfully to society.

PROBLEM STATEMENT

Engineering students face a multitude of challenges that can impact their academic performance, engagement, and overall well-being. One of the primary challenges is the high level of academic stress associated with rigorous engineering programs (Jensen et al., 2023). The demanding nature of engineering curricula, which often involves complex problem-solving tasks, technical assignments, and project-based learning, can lead to significant mental health concerns among students (Berry, 2005). These concerns are further exacerbated by the lack of representation of minoritised groups in engineering fields, creating an environment where students from diverse backgrounds may feel isolated or unsupported (Baumeister & Leary, 1995). In addition, academic facilitation can compound the learning experience through lack of management of student peer behaviour in teamworking and project activities, (Beddoes et al, 2018)

Cultural adaptation issues are another major challenge faced by international and minoritised students in engineering programs. Research by Zhou et al. (2008) highlights the difficulties that students experience when adapting to new cultural and educational environments. These adaptation challenges can lead to feelings of alienation, reduced self-esteem, and decreased academic performance. The absence of culturally responsive support systems within many engineering programs further amplifies these challenges, making it difficult for students to thrive academically and socially (Berry, 2005).

The attainment gap between minoritised students and their peers is a well-documented issue in higher education. According to Jones et al. (2017), minoritised students are more likely to face barriers to academic success, including implicit biases, microaggressions, and a lack of access to mentorship opportunities. These barriers contribute to lower retention and graduation rates among minoritised students in engineering programs. Addressing these barriers requires a comprehensive approach that includes both academic support and

initiatives aimed at promoting equality, diversity, and inclusion (Rubio et al., 2018; Williams, 2013).

Despite the emphasis on technical skills development, many engineering programs overlook the importance of interpersonal skills and psychological well-being in preparing students for the workforce. The CDIO framework aims to address this gap by promoting holistic education; however, there is still a lack of specific focus on student well-being within this framework (Jiang et al., 2023; Lambert et al., 2019). Positive Psychology Interventions (PPIs) provide a promising solution to this issue by fostering emotional resilience, promoting positive relationships, and enhancing students' overall well-being (Seligman, 2011).

Another key challenge is the disconnect between academic learning and industry practices. Plewa et al. (2013) emphasise that university-industry linkages are essential for preparing students for the realities of the workforce. However, many engineering programs fail to provide students with opportunities to engage with industry professionals or work on real-world projects. This disconnect can lead to a skills gap, where graduates lack the practical experience and soft skills needed to succeed in professional environments (Porter & Birdi, 2018). Addressing this gap requires integrating industry collaborations into the engineering curriculum, providing students with hands-on experience and exposure to industry practices.

The "Together Empowered" project addresses these challenges by integrating PPIs and EDI principles into the CDIO framework. By promoting student well-being, fostering a sense of belonging, and creating opportunities for meaningful industry engagement, the project aims to improve academic outcomes and prepare students for successful careers in engineering. The project recognises that addressing the attainment gap and promoting inclusivity requires more than technical interventions; educational institutions require a cultural shift to prioritise well-being and diversity (Rubio et al., 2018; Seligman et al., 2005).

PROJECT DESIGN AND IMPLEMENTATION

The "Together Empowered" project was designed and implemented in five distinct phases to achieve its objectives of promoting well-being, fostering cultural sensitivity, and bridging the gap between academia and industry. The project utilised a multi-pronged approach that incorporated Positive Psychology Interventions (PPIs) alongside industry collaboration to ensure both psychological and practical skill development in students.

Phase 1: EDI Awareness and Training (CDIO Standard 2, 7)

The first phase focused on raising awareness of Equality, Diversity, and Inclusion (EDI) issues within engineering programs. This phase contributed to learning outcomes related to personal and interpersonal skills (Standard 2), while also fostering integrated learning experiences related to inclusive team practices (Standard 7). Students were provided with training on recognising implicit biases, fostering inclusive environments, and addressing microaggressions. This phase aimed to prepare students to engage in culturally sensitive teamwork and develop solutions that consider diverse perspectives (Berry, 2005).

Phase 2: Industry Collaboration and Real-World Challenges (CDIO Standards 3,5)

In the second phase, students were paired with industry mentors to work on real-world projects that addressed societal challenges such as climate adaptation and sustainability. These real-world projects introduced early and advanced design-implement experiences (Standard 5) and connected technical and professional learning within an integrated curriculum (Standard

3). Industry representatives served as mentors and evaluators, offering feedback on students' solutions and helping them refine their ideas to meet industry standards (Plewa et al., 2013; Porter & Birdi, 2018).

Phase 3: Positive Psychology Workshops

This phase incorporated structured workshops based on the PERMA model to promote psychological resilience and well-being among students. These workshops included activities on mindfulness, stress management, gratitude practices, and character strengths identification. Emmons and McCullough (2003) demonstrated that gratitude practices could lead to improved subjective well-being, making it an essential component of these workshops. Students were encouraged to reflect on their learning experiences and apply positive psychology techniques to manage academic and social challenges (Butler & Kern, 2016). Also, the approach promotes a socially safe learning higher education environment and student learning active engagement from communication to creativity, (Kislyakov et al, 2014).

Phase 4: Development of Inclusive Solutions

In this phase, student teams worked collaboratively to develop inclusive solutions to the real-world challenges identified in Phase 2. Emphasis was placed on ensuring that solutions were culturally sensitive and accessible to diverse populations. Industry mentors provided feedback to ensure that solutions met both technical and social considerations (Rubio et al., 2018; Williams, 2013).

Phase 5: Evaluation and Dissemination

The final phase focused on evaluating the impact of the project and disseminating best practices to other higher education institutions. Surveys, reflective journals, and interviews were used to assess the effectiveness of the project in enhancing student well-being, engagement, and cultural sensitivity. Findings were shared through conferences, workshops, and academic publications to promote the adoption of similar initiatives across the engineering education sector (Jiang et al., 2023; Lambert et al., 2019).

The comprehensive, phased approach of the "Together Empowered" project highlights the importance of integrating EDI principles and PPIs into engineering education. By fostering cultural sensitivity, promoting well-being, and bridging the gap between academia and industry, the project aims to create a more inclusive and supportive learning environment that prepares students for successful careers in engineering.

Methodology

The project used a mixed-methods approach. Quantitative data were gathered using the validated PERMA Profiler (Butler & Kern, 2016) and pre/post assessments of key skills. Paired sample t-tests were conducted to determine statistical significance. Qualitative data were obtained from semi-structured interviews and student reflection journals. A thematic analysis approach was employed to identify key patterns in emotional well-being, engagement, and team experience. Data triangulation enhanced the credibility of the findings.

FINDINGS

The implementation of the “Together Empowered” project yielded significant improvements in student well-being, professional skills, and sense of belonging within the engineering

community. The study included a total of 90 participants, all of whom were either from BAME (Black, Asian, and Minority Ethnic) backgrounds or female. The demographic breakdown showed that 66.7% of participants identified as BAME, while 46.7% were female. This diverse representation aligns with the project's objectives to address attainment gaps and promote inclusion within engineering education. The findings presented here are based on quantitative data collected through the PERMA profiler, statistical analysis, and qualitative feedback from students and industry representatives.

The PERMA profiler scores captured substantial improvements across all five well-being dimensions post-intervention. These results highlight the positive impact of integrating Positive Psychology Interventions (PPIs) and Equality, Diversity, and Inclusion (EDI) principles within the CDIO framework.

Table 4- PERMA Profiler Scores

PERMA Dimension	**Pre-Intervention Score**	**Post-Intervention Score**	**Percentage Increase**
Positive Emotions	65	85	30%
Engagement	70	88	26%
Relationships	68	86	26.5%
Meaning	72	89	23.6%
Accomplishments	69	87	26.1%

A paired t-test was conducted to determine whether the improvements observed were statistically significant. The test yielded a t-statistic of 12.247 and a p-value of 0.0003, indicating that the improvements across all PERMA dimensions are statistically significant at the 0.01 level. This confirms that the intervention had a substantial positive impact on student well-being.

The most notable improvement was in the Positive Emotions category, where students reported feeling more optimistic and motivated to engage in academic and professional tasks

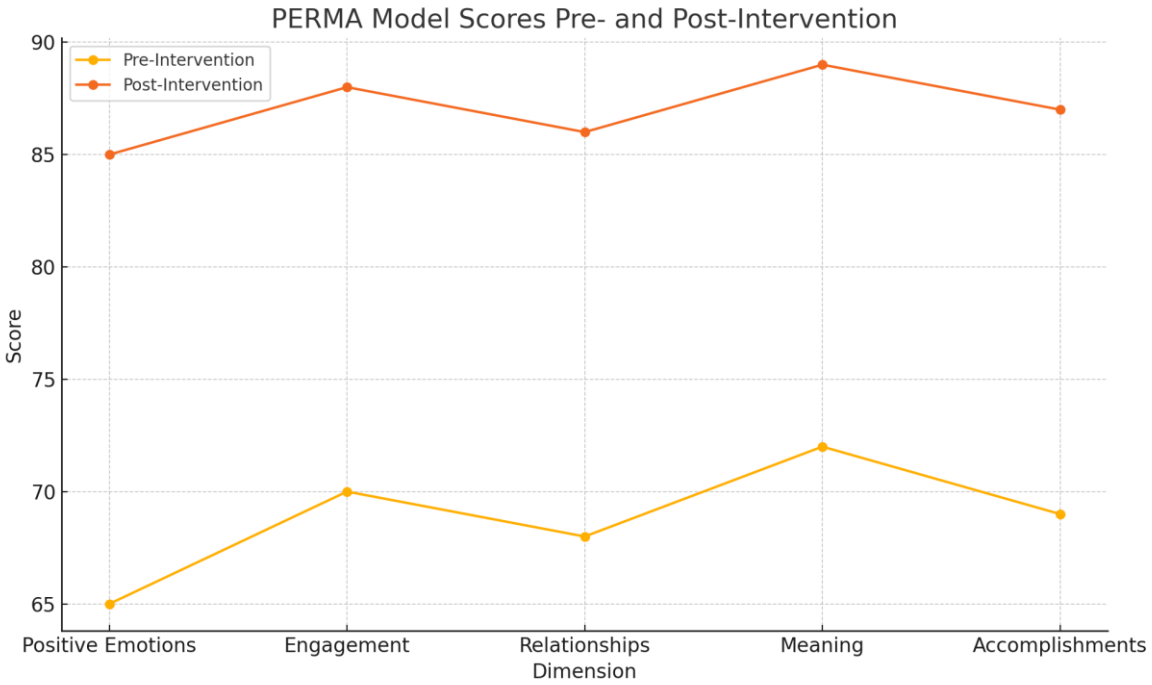


Figure 1. PERMA model scores pre-and post-intervention.

Student Feedback on Skills Improvement

The intervention significantly improved various professional skills, such as communication, teamwork, problem-solving, confidence, and cultural sensitivity.

Table 5- Pre- vs Post-Intervention Skills Scores

Skills Category	**Pre-Intervention Score**	**Post-Intervention Score**
Communication Skills	60	82
Teamwork	62	85
Problem-Solving	58	83
Confidence	65	88
Cultural Sensitivity	59	86

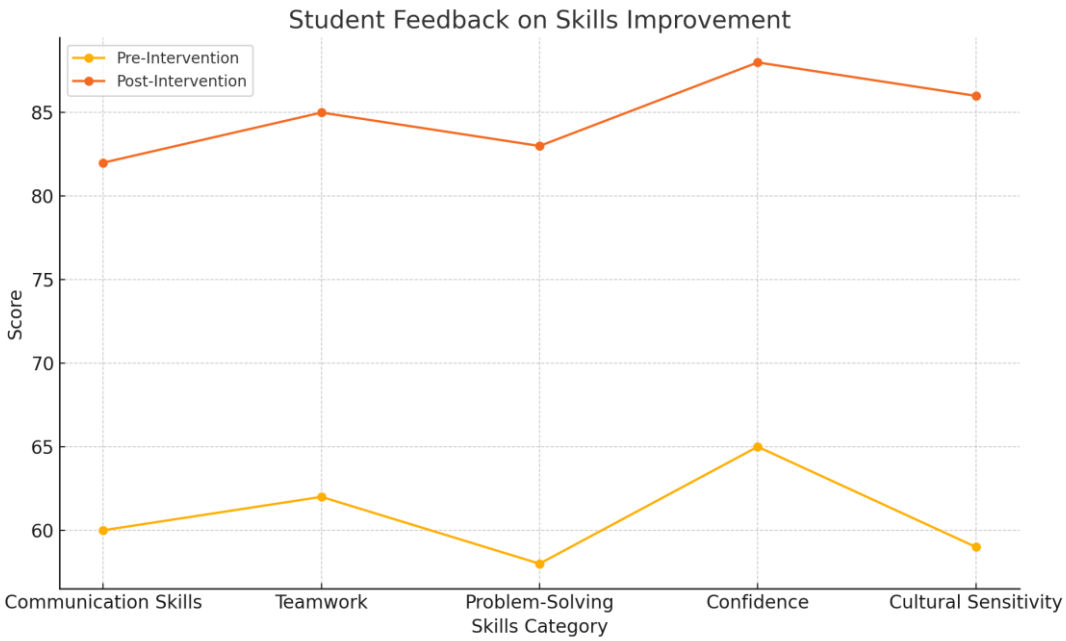


Figure 2. Student feedback on skills improvement.

Insights from Students

The qualitative feedback gathered from students provides deeper insights into how the intervention impacted their academic experiences and personal growth.

Emotional and Mental Well-Being Impact

Many students highlighted how the intervention contributed to reduced stress and improved mental well-being. The workshops on mindfulness, stress management, and positive psychology techniques equipped students with strategies to handle academic pressures more effectively.

Student Quote: *"The mindfulness sessions helped me deal with academic stress more effectively. I now approach challenges with a calmer mindset."*

Improved Cultural Sensitivity and Inclusion

The intervention increased students' awareness of the importance of cultural sensitivity and diversity in engineering projects. Many students reported a greater appreciation for inclusive teamwork practices.

Student Quote: *"Before this project, I didn't realise how important it was to consider cultural differences in team settings. It made me a better teammate and future engineer."*

Real-World Problem-Solving Skills

The project provided students with hands-on experience, allowing them to apply theoretical knowledge to real-world problems. This practical exposure enhanced their problem-solving skills and prepared them for future careers.

Student Quote: *"Working on real-world problems made the learning process more engaging. I felt like my work had a purpose beyond the classroom.*

Increased Confidence in Professional Interactions

The collaboration with industry mentors helped students build their confidence in presenting ideas and interacting with professionals. The feedback from mentors reinforced their skills and motivated them to pursue their career goals.

Student Quote: *"Presenting my ideas to industry mentors was intimidating at first, but their feedback helped me grow. I now feel more prepared for job interviews and professional discussions."*

Industry Feedback

Industry mentors provided valuable insights into the intervention's success. They recognised the collaboration's mutual benefits and appreciated the students' innovative approaches.

Industry Rep1: "The students' ability to think outside the box and address complex challenges was impressive."

Industry Rep2: "We gained fresh ideas from the students, and the collaboration was mutually beneficial."

Industry Rep3: "The emphasis on inclusivity and cultural sensitivity in the project was a refreshing approach, aligning well with our company's values."

DISCUSSION

The findings from the "Together Empowered" project highlight the effectiveness of integrating Positive Psychology Interventions (PPIs) and Equality, Diversity, and Inclusion (EDI) principles within the CDIO framework to address the challenges faced by engineering students. This discussion explores the broader implications of these findings in the context of engineering education, emphasising how holistic interventions can bridge the gap between technical training and essential soft skills development.

Addressing Well-Being in Engineering Education

Engineering education traditionally focuses on developing technical competencies, often overlooking the importance of students' emotional and mental well-being. The "Together Empowered" project demonstrates that addressing well-being through PPIs can significantly enhance students' overall academic experience. The improvement in Positive Emotions, Engagement, and Relationships categories within the PERMA model underscores the critical role that well-being plays in fostering academic motivation and resilience. These results align with existing research emphasising that students who feel emotionally supported and engaged are more likely to succeed academically and professionally (Seligman, 2011).

Enhancing Cultural Sensitivity and Inclusion

One of the unique aspects of the "Together Empowered" project was its focus on promoting cultural sensitivity and inclusion within engineering teams. The increased awareness of cultural differences reported by students highlights the importance of fostering inclusive teamwork practices in academic settings. In a globalised world, engineers must be equipped to work effectively in diverse teams, making cultural competence an essential skill. The

project's emphasis on EDI principles prepared students to navigate real-world engineering challenges with empathy and understanding, thus enhancing their employability.

Student Quote: *"Before this project, I didn't realize how important it was to consider cultural differences in team settings. It made me a better teammate and future engineer."*

The collaboration with industry mentors further reinforced the importance of inclusion in professional practice. Industry representatives valued the project's focus on diversity, recognising it as a critical factor in developing innovative and socially responsible engineering solutions.

Industry Quote: *"The emphasis on inclusivity and cultural sensitivity in the project was a refreshing approach, aligning well with our company's values."*

Bridging the Academia-Industry Gap

The project also addressed a long-standing challenge in engineering education—the gap between academic learning and industry expectations. By involving industry mentors in the intervention, students gained practical insights into real-world engineering problems and professional practices. This hands-on experience not only improved their technical skills but also helped them develop soft skills such as communication, teamwork, and problem-solving.

Student Quote: *"Working on real-world problems made the learning process more engaging. I felt like my work had a purpose beyond the classroom."*

The feedback from industry mentors was overwhelmingly positive, with many expressing appreciation for the students' ability to address complex challenges creatively. These interactions helped students build confidence in presenting their ideas and engaging with professionals, which is essential for career readiness.

Industry Quote: *"The students' ability to think outside the box and address complex challenges was impressive."*

The Role of Positive Psychology in Education

The integration of the PERMA model into the intervention provided a structured framework for enhancing student well-being. The statistical analysis of the PERMA scores showed significant improvements across all dimensions, indicating the effectiveness of PPIs in fostering emotional resilience and engagement. These results support the growing body of literature advocating for the inclusion of positive psychology principles in education to promote student flourishing (Butler & Kern, 2016).

The intervention also highlighted the importance of addressing mental health in academic settings. Many students reported that the mindfulness and stress management sessions helped them cope more effectively with academic pressures.

Student Quote: *"The mindfulness sessions helped me deal with academic stress more effectively. I now approach challenges with a calmer mindset."*

By promoting psychological well-being, the project created a supportive learning environment where students felt empowered to overcome challenges and achieve their goals.

IMPLICATIONS FOR FUTURE PRACTICE

The findings from the “Together Empowered” project have important implications for the future of engineering education. First, they demonstrate that well-being and EDI initiatives can be successfully integrated into technical programs without compromising academic rigour. Second, the project shows that university-industry collaborations can enhance the learning experience by providing students with practical exposure to professional practices and real-world challenges.

This project aligns particularly well with CDIO Standard 2 by explicitly targeting interpersonal and intrapersonal skills such as communication, teamwork, cultural competence, and well-being. It also exemplifies Standard 7 by providing integrated learning experiences through industry-based challenges and teamwork. The project's emphasis on PERMA-based active workshops reflects Standard 8. Importantly, the structured integration of these elements across the curriculum and collaboration with industry support Standard 3 and Optional Standard 1 (Sustainable Development).

Educational institutions must adopt a holistic approach that prioritises technical training and personal development to maximise the impact of such interventions. The CDIO framework provides an ideal structure for implementing these changes, as it emphasises the importance of developing well-rounded engineers who are prepared to address the complex challenges of the modern world.

Practical Recommendations for Educators

- Embed PERMA-based PPIs into design-implement projects: Introduce short reflective activities on gratitude, personal strengths, and goal-setting into project modules to foster well-being.
- Train facilitators in inclusive team management: Include EDI training for instructors to better support culturally diverse student groups.
- Collaborate with industry on socially impactful briefs: Encourage industry mentors to co-design challenges that combine technical complexity with social relevance, aligning with CDIO’s sustainability goals.
- Monitor well-being alongside academic progress: Use tools like the PERMA Profiler at the start and end of key modules to track student well-being and tailor support mechanisms.

Limitations and Future Research

While the results of the “Together Empowered” project are promising, it is important to acknowledge its limitations. The sample size was relatively small, and the intervention was conducted within a specific cultural and educational context. Future research could explore the long-term impact of similar interventions across different institutions and cultural settings.

Additionally, future studies could investigate the specific components of the intervention that had the greatest impact on student outcomes. This would help educators refine their approaches to promoting well-being and inclusivity in engineering education.

In conclusion, the “Together Empowered” project highlights the potential of integrating positive psychology and EDI principles within the CDIO framework to enhance student well-being, foster essential skills, and prepare students for successful careers in engineering. The findings underscore the importance of holistic education models that address both technical and

interpersonal competencies, paving the way for more inclusive and supportive learning environments in the future.

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INTEGRATING LANGUAGE LEARNING IN ENGINEERING EDUCATION: A CDIO APPROACH AT ETUT

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ABSTRACT

This study investigates the integration of language learning within engineering education using the CDIO (Conceive, Design, Implement, Operate) framework at Oguz han Engineering and technology university of Turkmenistan (ETUT). The research aims to enhance both language proficiency and technical communication skills among engineering students, addressing the growing need for effective communication in a globalized workforce. A comparative study was conducted over a 12-week period, involving two groups of 25 students each. One group followed a CDIO-based curriculum, while the other used traditional teaching methods. The effectiveness of the approach was evaluated through pre- and post-tests assessing both technical knowledge and language skills. Results show that students in the CDIO group (hereinafter Group B) improved their overall performance by 19%, achieving an average score of 78% compared to 68% in the traditional group (hereinafter Group A). These findings suggest that a balanced application of the CDIO phases can effectively foster an educational environment that promotes linguistic competence alongside engineering excellence. This research contributes to the ongoing discussion on innovative approaches in engineering education, highlighting the potential of the CDIO framework in preparing students for successful careers in an increasingly interconnected world.

KEYWORDS

CDIO Framework, Language Learning in Engineering, CDIO method, Technical Communication Skills, Educational Methodologies, Standard 2,3,11.

INTRODUCTION

Context and Importance

In today's globalized world, the ability to communicate effectively in English is paramount, especially in engineering fields where collaboration often spans international borders. As engineering education evolves to meet the demands of a diverse and interconnected workforce, integrating language learning into the curriculum has become increasingly significant. Effective communication skills not only enhance students' understanding of technical concepts but also prepare them for real-world challenges where they must articulate ideas clearly and collaborate with peers from various cultural backgrounds (Leong, 2016). This integration is particularly crucial at ETUT, where students are being equipped to thrive in a competitive global market. The university offers a preparatory course before the bachelor's degree, during which we implemented the CDIO approach discussed in this paper.

Objectives of the Paper

This paper aims to explore the integration of language learning within engineering education through the application of the CDIO (Conceive, Design, Implement, Operate) framework. It focuses on how this approach can address specific challenges associated with Content and Language Integrated Learning (CLIL) and Project-Based Learning (PBL). By examining these frameworks, the research seeks to identify effective strategies for enhancing both language proficiency and technical communication skills among engineering students.

Study Rationale

While integrating language learning through the CDIO framework offers a promising pathway to enhance technical communication skills among engineering students, it is essential to address challenges such as the shifting focus from language acquisition to content mastery and the insufficient development of communication skills. This paper argues that a balanced application of CDIO phases can mitigate these challenges, fostering an educational environment that promotes both linguistic competence and engineering excellence.

THEORETICAL FRAMEWORK

Overview of CDIO

The CDIO (Conceive, Design, Implement, Operate) framework is a comprehensive educational model designed to enhance engineering education by focusing on the entire lifecycle of products, processes, and systems. It emphasizes the integration of technical knowledge with practical skills, ensuring that students are well-prepared for the challenges of modern engineering practice (Crawley et al., 2014). The CDIO (Conceive-Design-Implement-Operate) framework has been widely adopted to enhance engineering education by incorporating practical, real-world learning experiences. Recent studies have explored its application in language learning for engineering students. For instance, Weerakoon and Dunbar (2018) propose a structured approach that aligns second language acquisition with engineering learning outcomes, ensuring that communication skills are developed alongside technical expertise. Similarly, Wu et al. (2012) discuss the implementation of the CDIO concept in bilingual education, highlighting its effectiveness in non-English-speaking environments for courses such as Digital Image Processing. These studies underscore the importance of integrating language learning into engineering curricula, promoting both technical proficiency and communication skills essential for professional success.

The CDIO framework not only promotes disciplinary knowledge but also focuses on personal and interpersonal skills essential for effective teamwork and communication in engineering environments.

Introduction to Language Learning Frameworks for Engineering students

The importance of integrating language skills in engineering education is increasingly recognized, as seen in the work of Rinder et al. (2020) and other studies. Content and Language Integrated Learning (CLIL) is an educational approach that combines language learning with subject content instruction. It aims to foster language acquisition in meaningful contexts by using a foreign language as the medium of instruction for subjects such as science or mathematics (Coyle et al., 2010). CLIL encourages active engagement and promotes cognitive skills by integrating language practice with content learning (Mehisto et al., 2008).

Project-Based Learning (PBL), on the other hand, is an instructional methodology that engages students in real-world projects over extended periods. PBL emphasizes student-centered learning, critical thinking, collaboration, and communication skills as students work together to solve complex problems (Thomas, 2000). While both CLIL and PBL have proven effective in enhancing language proficiency and subject-specific knowledge, they also present challenges. For instance, there can be a tendency for students to focus more on content mastery at the expense of developing their language skills, leading to insufficient communication abilities in professional contexts (Ball et al., 2015).

Intersection of Frameworks

Integrating CDIO with CLIL and PBL creates a powerful synergy for engineering education, addressing language acquisition challenges. CDIO provides a structured framework for CLIL, offering practical contexts for language use within engineering problems. Similarly, CDIO enhances PBL by structuring project development and emphasizing communication throughout.

CDIO's phases scaffold language learning in project activities, especially during the "Operate" phase, where students present projects using technical knowledge and advanced language skills. This approach ensures that students not only engage deeply with content but also develop their ability to communicate complex ideas clearly throughout the learning process (Crawley et al., 2014; Rinder, J. et al.,2016).

By combining CDIO's practical application, CLIL's content-language integration, and PBL's collaborative focus, educators create a comprehensive learning environment. This prepares students for engineering careers where both technical expertise and effective communication are essential.

CURRICULUM COMPARISON

Previous Curriculum: General English

ETUT's prior curriculum emphasized General English, Japanese, and Turkmen, aiming for communicative competence in four key skills via traditional methods like grammar drills. However, students, though proficient in general English, lacked technical language skills necessary for engineering (Zhou, 2015). Feedback revealed a gap in discipline-specific vocabulary and context, hindering their ability to articulate complex engineering concepts

(Sanchez Palacios, 2021). This necessitates a more engineering-focused language curriculum. The distribution of study hours across different courses can be seen in the accompanying table. See Table 1.

Table 1: Distribution of Study hours in the Previous Curriculum

	Name of the courses	Distribution by three periods			
		Total number of hours	1st Trimester Number of hours	2nd Trimester Number of hours	3rd Trimester Number of hours
1	Turkmen	72	24	24	24
2	Japanese	396	132	132	132
3	English	1044	348	348	348
	Total:	1512	504	504	504

Current Curriculum: Scientific English + General English

To address the lack of engineering-specific language skills, ETUT's revised curriculum now integrates Scientific English alongside General English. Scientific English focuses on technical vocabulary and reading comprehension through scientific texts, covering subjects like physics and mathematics, preparing students for professional communication (Chen et al., 2024). General English maintains broader language skill development, ensuring a well-rounded linguistic education. Table 2 shows the distribution of study hours, including optional engineering subjects.

Table 2: Distribution of Study hours in the Current Curriculum

	Name of the courses	Distribution by three periods			
		Total number of hours	1st Trimester Number of hours	2nd Trimester Number of hours	3rd Trimester Number of hours
1	Turkmen	72	24	24	24
2	Japanese	396	132	132	132
3	English	720	240	240	240
4	Optional subjects	324	108	108	108
	Total:	1512	504	504	504

Note: 1. Computer science, physics, mathematics, biology, and chemistry courses are taught in English.

CHALLENGES FACED

Focus Shift in Language Learning Frameworks for Engineering Students

CLIL and PBL, while beneficial, pose challenges to language acquisition. CLIL risks prioritizing content over English articulation, leading to strong subject knowledge but weak communication (Uemura, 2017; Pratap & Alapati, 2020). Similarly, PBL's project focus can overshadow language development, with students neglecting English proficiency for project completion (Peachey Publications, 2024; Zhang, 1992). Both methods require careful

integration of language objectives to ensure balanced content mastery and communication skills.

Challenges of Language Variability in Technical education

Another significant challenge is the variability in language proficiency among students within integrated curricula. In any given classroom, students may possess varying levels of English proficiency, which can create disparities in participation and learning outcomes. Those with lower proficiency levels may struggle to engage fully with both the content and the language components of the curriculum, leading to feelings of frustration and disengagement (Su, 2008). This variability necessitates differentiated instructional strategies that accommodate diverse learning needs while ensuring that all students have opportunities to develop both their technical knowledge and language skills effectively (Rinder, J. et al.,2016).

Assessment Methods

Finally, assessing both language skills and engineering knowledge presents its own set of challenges. Traditional assessment methods often prioritize content knowledge over language proficiency, making it difficult to evaluate students' overall competence effectively (Ball et al., 2015). Furthermore, developing fair and transparent assessment criteria that recognize collaboration while rewarding individual effort can be complex within project-based contexts (Peachey Publications, 2024). Educators must create assessment frameworks that capture both linguistic competencies and technical understanding to provide a holistic view of student performance.

EXPERIMENTATION METHODOLOGY - APPLICATION OF CDIO PHASES AS A SOLUTION

Experimental Design

In this research, the CDIO (Conceive, Design, Implement, Operate) approach was implemented in a preparatory course at ETUT to evaluate its effectiveness compared to traditional teaching methods. The study involved two groups, each consisting of 25 students. Students were assigned to either the traditional group (Group A) or the CDIO group (Group B) based on random assignment to ensure equal distribution of prior language proficiency. Group A followed the traditional instructional method, while Group B engaged in the CDIO approach, incorporating elements of Content and Language Integrated Learning (CLIL).

The study spanned 12 weeks during the second trimester. Each 80-minute lesson was structured around one of the CDIO phases. Both groups underwent a pre-test at the beginning of the course to assess their initial language proficiency and understanding of engineering concepts. The pre-test assessed their ability to understand and explain basic engineering principles in English, including vocabulary, grammar, and reading comprehension related to technical topics. It included a combination of multiple-choice questions, short-answer questions. A post-test was administered after the course to evaluate their progress in both areas. The post-test evaluated the same skills as the pre-test, but with more complex engineering concepts and a greater emphasis on technical writing and oral communication. It included problem-solving questions, a technical report writing assignment.

Group A primarily followed lecture-based instruction, where students passively listened to lecturers and were expected to comprehend and process the material independently. In

contrast, Group B was divided into five smaller groups of five students each, with one team leader per group. Lessons were designed to actively engage students through the CDIO phases, integrating engineering topics with English language learning. The following describes the implementation of each CDIO phase for Group B:

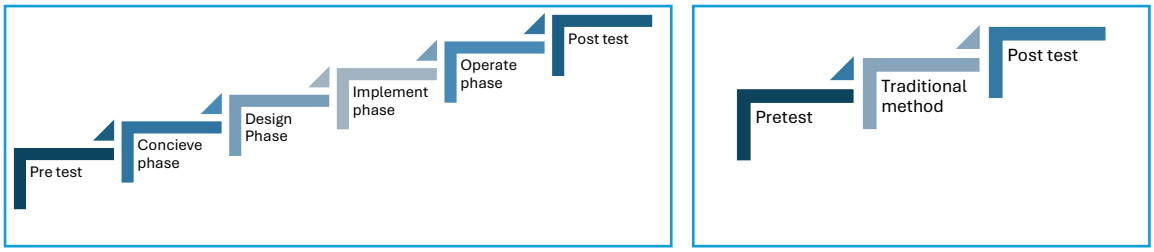


Figure 1. On the left side, the 'CDIO' teaching method; on the right side, the 'Traditional' teaching method

Conceive Phase

In this phase, students explored the topic of the lesson under lecturer guidance. They were encouraged to search for information online related to engineering subjects integrated with English. For example, in a lesson on "Movement," students learned about directional movement concepts relevant to fields such as robotics, mechatronics, and transportation.

- Content Focus: Engineering topics like how objects move (e.g., fluid flow or electric current).
- Grammar: Adverbials of direction (e.g., "can," "cannot," "imperative + present simple," "when clause").
- Vocabulary: Engineering-specific terms such as "up," "down," "forwards," "vertically," "degrees," "ascend," "descend," "joystick," and "slider."

Students worked individually or in pairs to research these concepts and grammar rules online or through lecturer-provided materials. This phase allowed them to build foundational knowledge for subsequent phases.

Design Phase

In this phase, students worked cooperatively while the lecturer acted as an observer and facilitator. The focus was on organizing information collected during the Conceive Phase.
- Students collaborated within their groups to create sentences using:
  - Lesson content (e.g., movement principles).
  - New vocabulary (e.g., "ascend" or "descend").
  - Grammar structures learned earlier (e.g., adverbials of direction and zero conditional sentences).
- Team leaders divided tasks among group members to ensure equal participation.
- The lecturer provided clarification and resolved any issues that arose during group discussions.

This phase emphasized teamwork and critical thinking as students synthesized information into coherent ideas.

Implement Phase

During this phase, students transformed their collected data into a formal presentation.

- Group members discussed their findings and exchanged opinions while preparing slides or other visual aids.
- They integrated vocabulary, grammar structures, and engineering concepts into their presentations.
- The lecturer provided guidance when necessary but allowed students to take ownership of their work.

This phase encouraged creativity and collaboration while reinforcing both language skills and technical understanding.

Operate Phase

In the final phase, each group presented their projects to the class.
- Presentations included:
  - A demonstration of materials used.
  - An explanation of strategies employed during research and preparation.
  - Examples showcasing how they applied vocabulary, grammar, and engineering concepts.
- After each presentation:
  - The lecturer provided structured feedback on both technical content and communication skills.
  - Other groups offered peer feedback based on predefined criteria.

This phase helped students refine their public speaking skills while reflecting on their learning process.

RESULTS AND DISCUSSION

Findings Overview

The data collected from the pre-tests and post-tests provided valuable insights into students' attitudes toward language integration in their engineering education. The performance of both groups was assessed based on their pre- and post-test results; however, their communication skills could not be evaluated in the same way due to differences in their learning approaches. Students in Group B expressed a positive attitude toward the integration of language learning with technical content. Many reported that the structured phases of the CDIO approach created a more engaging and interactive learning environment. Feedback indicated that students appreciated the collaborative nature of group work, which not only enhanced their understanding of engineering concepts but also improved their ability to communicate effectively in English. Additionally, students noted that the emphasis on real-world applications made the learning experience more relevant and motivating.

Pre-Test vs. Post-Test (Paired t-test)

The paired t-test revealed a significant improvement in the group B performance from pre-test to post-test ($t(df) = 4.899$, $p = 0.0000117$). This indicates that the CDIO framework effectively enhanced students' language proficiency and technical knowledge over the course of the study period. The extremely low p-value provides strong evidence against the null hypothesis.

Group A vs. Group B (Independent t-test)

The independent t-test showed no statistically significant difference between the post-test scores of the group B and the traditional group ($t(df) = 2.92$, $p = 0.05311$). While there was a

numerical difference in favor of the group B, the p-value is above the conventional significance level of 0.05, indicating that the observed difference may have occurred by chance.

Table 3: Statistical Analysis of group A and B Performance: t-test Results

Test Type	Mean (CDIO)	Mean (Comparison)	t-value	p-value
Paired t-test	Pre: 67.57%	Post: 78.42%	4,89015	0.0000117
Independent t-test	Group B: 78.42%	Group A: 68%	2,92009	0.005316311

Impact on Learning Outcomes

The implementation of the CDIO (Conceive, Design, Implement, Operate) framework at ETUT effectively enhanced student performance, addressing challenges often associated with CLIL and PBL. As shown in Figure 2, Group B (CDIO) improved by 19.01% from pre-test (59.41%) to post-test (78.42%), outperforming Group A by 10.85% on the post-test.

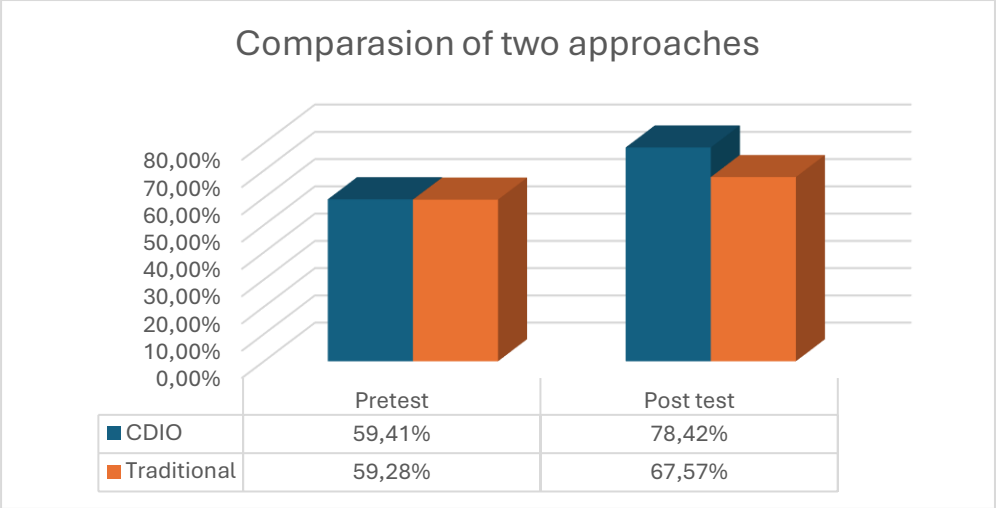


Figure 2. Results of the pre-test and post-test for the two groups.

CDIO's structured phases balanced technical knowledge with language development. The "Conceive" phase allowed students to address real-world problems while practicing communication skills. The "Design" phase fostered collaborative learning, reinforcing both technical and language abilities. During "Implement and Operate," students presented projects, receiving feedback that improved their confidence and communication of complex ideas.

Overall, the CDIO framework fostered a synergistic learning environment, preparing students for global engineering careers by effectively integrating technical content with language proficiency, addressing the focus shift issues common in CLIL and PBL.

CONCLUSION

The integration of language learning within engineering education through the CDIO framework represents a significant advancement in addressing the challenges students face

in acquiring both technical knowledge and effective communication skills. Findings from our study at ETUT demonstrate that the CDIO approach fosters active engagement and collaborative learning, leading to improved academic performance and enhanced language proficiency. By structuring lessons around the CDIO phases, educators can create a dynamic learning environment that emphasizes both technical content and essential communication skills. This integrated approach equips students with the competencies necessary to thrive in a globalized workforce.

While this study provides valuable insights into the immediate benefits of the CDIO approach, the relatively small sample size (n=25 per group) suggests that the findings should be interpreted with caution. Future research with larger cohorts is needed to confirm these results and explore the broader applicability of the CDIO approach. Further research could also explore the long-term impacts on graduates' employability and communication skills. Specifically, future studies could investigate how well-prepared students feel upon entering the workforce and whether their experiences with integrated language learning influence their professional success. Additionally, longitudinal research could assess how the skills developed through the CDIO framework contribute to overall educational outcomes, including critical thinking and adaptability.

In conclusion, integrating language learning within engineering education through the CDIO phases not only addresses current challenges but also lays a foundation for developing well-rounded graduates equipped to meet the demands of an increasingly interconnected world. This study contributes to the existing body of knowledge by demonstrating the effectiveness of the CDIO framework in enhancing both language proficiency and technical communication skills among engineering students in an engineering program.

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BIOGRAPHICAL INFORMATION

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APPENDIX

Due to confidentiality reasons, only a small portion of the pre-test can be shared. Below is a sample excerpt from the pre-test:

1. Which of the following sentences is grammatically correct?

   a) I have been waiting for her since two hours.

   b) I have been waiting for her for two hours.

   c) I am waiting for her since two hours.

   d) I wait for her for two hours.

2. “To put something off" means:

   a) To complete something quickly.

   b) To postpone or delay something.

   c) To find something easily.

   d) To understand something clearly.

3. Choose the correct form of the verb in the sentence: "If I _____ more time, I would travel the world."

   a) have

   b) had

   c) will have

   d) am having

4. Which preposition best completes the sentence: "She is very good _____ playing the piano."

   a) at

   b) in

   c) on

   d) for

5. "He is always complaining; he's such a _____."

   a) optimist

   b) pessimist

   c) realist

   d) idealist

6. Which sentence uses the passive voice correctly?

   a) The dog chased the cat.

   b) The cat was chased by the dog.

   c) The cat chases the dog.

   d) The dog is chasing the cat.

Below is a sample excerpt from the post-test:

1. What is the term for moving down?
   - A) Ascend
   - B) Descend
   - C) Flow
   - D) Slide
2. Which word means to move up?
   - A) Down
   - B) Forwards
   - C) Ascend
   - D) Backwards
3. What do we use to control movement in robotics?
   - A) Joystick
   - B) Hammer
   - C) Screwdriver
   - D) Wrench
4. What does "fluid flow" mean?
   - A) The movement of solids
   - B) The movement of liquids and gases
   - C) The movement of light
   - D) The movement of sound
5. Which sentence is an example of a command?
   - A) You should check the connections.
   - B) Please turn on the device.
   - C) If you press the button, it will move.
   - D) I will fix it later.
6. What does "forwards" mean?
   - A) Moving back
   - B) Moving ahead
   - C) Moving sideways
   - D) Staying still

BUILDING SCALABLE INDUSTRY COLLABORATION IN ENGINEERING EDUCATION THROUGH THE CDIO FRAMEWORK

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ABSTRACT

TheFIRMA is an ICT learning environment located at Turku University of Applied Sciences (TUAS), Finland. It was established in 2015 through the merger of several previous learning environments. Over the past decade, theFIRMA has evolved into a scalable and dynamic platform that exemplifies how industry collaboration can be integrated into engineering education using the CDIO (Conceive-Design-Implement-Operate) framework, effectively bridging academic theory with real-world, project-based learning experiences. The aim of this paper is to analyze how theFIRMA has applied CDIO principles to foster authentic learning experiences and align educational outcomes with industry demands. The scope encompasses the project office's establishment, key milestones, and its dual impact on students and industry stakeholders. By participating in projects such as web and app development, graphical design, and end-user training, students gain disciplinary knowledge and personal and interpersonal skills. Industry partners benefit from cost-effective solutions and access to emerging talent. Key milestones include the establishment of the competence track, increased engagement in projects, and participation in externally funded R&D initiatives. These developments have been underpinned by CDIO Standards – notably standard 6. Engineering Learning Workspaces, standard 7. Integrated Learning Experiences, and standard 8. Active Learning – which have shaped theFIRMA's practices and outcomes. The conclusion emphasizes theFIRMA's role in preparing students for successful careers while strengthening ties with industry. Despite challenges such as balancing academic schedules and project demands, theFIRMA's innovative strategies have ensured continuity and impact. As it embarks on its second decade, plans include expanding international collaborations, enhancing digital assessment tools, and deepening long-term industry partnerships. This paper provides insights into theFIRMA's journey while enriching engineering education through CDIO implementation and industry engagement.

KEYWORDS

University-industry collaboration, project-based learning, ICT, R&D learning environment, Standards: 6, 7 and 8.

INTRODUCTION

IT engineering education faces a constant challenge to keep pace with rapid technological advancements and evolving industry requirements. Employers increasingly emphasize not only technical expertise but also transferable skills such as problem-solving, adaptability, teamwork, and communication. The World Economic Forum's "Future of Jobs Report 2020" identifies analytical thinking and innovation, active learning and learning strategies, complex problem-solving and emotional intelligence as essential skills for the future workforce. Similarly, studies by Binkley et al. (2012) and Van Laar et al. (2017) underscore the importance of 21st-century skills, including communication, collaboration, leadership, and digital literacy. For engineering educators, it is important to incorporate employability skills into the curriculum to effectively prepare graduates for successful careers in the engineering sector (Manna, Joyce & Nortcliffe, 2023).

The CDIO framework provides a robust foundation for modernizing curricula to ensure students graduate with relevant and practical skills. Its emphasis on active learning, hands-on projects, and interdisciplinary teamwork aligns well with contemporary industry expectations (Crawley et al., 2014). CDIO Standards (cdio.org), particularly Standard 6 (Engineering Learning Workspaces), highlight the importance of providing students with professional environments that support collaboration and practical learning, Standard 7 (Integrated Learning Experiences) focuses on combining technical knowledge with personal and interpersonal skill development, and Standard 8 (Active Learning) emphasizes experiential methods that engage students in real-world problem-solving.

In this context, theFIRMA was conceived as a scalable learning environment to bridge the gap between academic theory and industry practice, fostering authentic learning experiences through real-world projects. A core feature of theFIRMA is its focus on integrating disciplinary knowledge and personal and interpersonal skills into engineering education. By working in teams on client-driven assignments, students learn to manage timelines, communicate with stakeholders, and address unforeseen challenges – competencies that are essential for employability (Andrews & Higson, 2008).

This paper explores theFIRMA's ten-year journey, analyzing its alignment with the CDIO framework and its contribution to the theme of "Industry Collaboration and Perspectives." It highlights how scalability has been a central consideration in theFIRMA's design, enabling the model to adapt and grow to meet increasing demands from students and industry partners. We discuss the integration of CDIO principles into theFIRMA's operations, highlight key milestones, and reflect on the lessons learned from a decade of project-based industry-focused education.

THE EVOLUTION OF THEFIRMA

Establishment and objectives

TheFIRMA was established in 2015 by consolidating multiple learning environments within TUAS' ICT unit. Its primary goal was to provide students with hands-on learning opportunities by participating in real customer projects. TheFIRMA operates like a company, offering services such as web and app development, graphical design, and end-user training to small and medium-sized enterprises (SMEs) and other organizations (Säisä, Määttä, & Roslöf, 2017). More detailed case references are presented on theFIRMA website: https://thefirma.fi/. The establishment of theFIRMA combined the strengths of earlier learning environments

“Education Support Centre Finland,” “Network Support Centre Finland,” “ICT-portti,” and “Citizen’s Helpdesk” to create a unified, scalable, and student-driven learning environment. The integration of these learning environments aimed to streamline operations, establish consistent processes, and broaden the scope of activities, ensuring a more efficient and impactful learning platform for students (Säisä, Määttä, & Roslöf, 2017).

Aligned with CDIO Standards 6 (Engineering Learning Workspaces), 7 (Integrated Learning Experiences), and 8 (Active Learning), theFIRMA aims to: 1) Integrate interdisciplinary skills into project-based learning, 2) Foster collaboration between academia and industry, and 3) Equip students with personal and professional competencies essential for their careers.

Key Milestones

2015-2017: Establishing Operations

The initial phase of theFIRMA focused on consolidating multiple learning environments to form a unified structure within the TUAS ICT unit. TheFIRMA operates as a student-led organization, with a student CEO overseeing operations, student project managers coordinating projects, and a student marketing manager handling promotional activities (Määttä, Roslöf & Säisä, 2018). In the beginning, a few dozen students were working in theFIRMA on yearly basis.

As the number of projects and students at theFIRMA grew, it became necessary to implement a more structured approach to manage the increasing activity. Beginning in the academic year 2016–2017, a course titled *ICT Services and Projects* was introduced to establish an organized framework for theFIRMA’s operations (Määttä, Roslöf & Säisä, 2018). Course was available as a free-choice course for all the ICT students. Course faced challenges, including a high dropout rate caused by students underestimating the course requirements, overestimating their time management skills, and being unprepared for the responsibility tied to customer projects, which led to staffing shortages, delays in internal development projects, and additional workload for both teaching staff and student project managers who had to handle the fallout from disappearing participants (Määttä, Roslöf & Säisä, 2018).

In 2016, theFIRMA competence track was launched as a pilot program, admitting approximately ten motivated students annually from information and communication technology and business information systems programs. Instead of traditional classroom learning, these students developed their skills by working on theFIRMA’s client projects.

Additionally, theFIRMA engaged in externally funded R&D projects, such as "SparkUp Portti" which provided opportunities to pilot and validate implemented project and learning processes while expanding its visibility among industry partners.

2018-2020: Expanding Scope

Building upon its foundation, theFIRMA shifted focus to broadening its operational scope and enhancing learning opportunities. In 2020, the official Software Engineering and Project Management (SEPM) competence track was introduced, with 32 students selected in its first year. Alongside project work, this track incorporated theoretical lessons and practical exercises to support skill development. The program quickly gained popularity, and after the first year, 65–79 motivated students with versatile and multicultural backgrounds have been admitted annually.

During this period, international collaboration efforts were also strengthened through cooperation with AGILE@SoC, a project-based learning environment established at Singapore Polytechnic in 2019 (Säisä et al. 2020). The partnership facilitated joint projects, enabling students to develop interdisciplinary and intercultural competencies while working on real-world assignments across institutions (Säisä et al. 2020).

During 2018–2020, several externally funded R&D projects were launched to address digitalization and sustainability challenges. Projects such as Inside the Box and Hot Potato focused on advancing the digitalization of SMEs. Additionally, TRY OUT! and Open DaaS concentrated on developing digital solutions to promote circular economy practices. These initiatives emphasized multidisciplinary collaboration, bringing together students and faculty from various fields to tackle complex challenges, foster innovation, and support teamwork-driven problem-solving.

2021-2025: Scaling Impact

In the most recent phase, theFIRMA has prioritized enhancing quality, leveraging digitalization, and strengthening partnerships to ensure long-term impact. Quality improvements have focused on refining assessment tools, standardizing project workflows, and incorporating feedback mechanisms to optimize learning outcomes and project performance. Digitalization has played a central role in modernizing operations, including the implementation of advanced digital platforms for project management, communication, and performance tracking. These tools have improved efficiency, transparency, and collaboration in theFIRMA projects. Moving forward, this phase aims to reinforce these developments while maintaining adaptability to evolving industry needs.

In 2023–2024, theFIRMA collaborated with Open ICT, part of the University of Applied Sciences Utrecht in the Netherlands, to promote international project-based learning. As part of the partnership, projects were carried out simultaneously in both countries, enabling students to work across borders, exchange knowledge, and enhance their technical and teamwork skills through real-world assignments.

Between 2021 and 2025, theFIRMA has been involved in several R&D projects. Pelimo promoted multicultural education with a mobile game for schools. EntreFox supported 55+ entrepreneurs' well-being and skills. VERKKO offered business coaching for entrepreneurs in Southwest Finland. DigiReactor developed digital product development skills and built a digital product platform, and Digio advanced digital solutions for small businesses.

Currently, over 200 students participate in theFIRMA each year as part of their studies. Most of the students are from dedicated SEPM competence track, but some of the students are from other competence tracks of ICT unit of TUAS. They can choose tasks aligned with their interests, such as project management, web programming, app programming, testing, and UI/UX design. This flexible structure allows students to build personalized learning paths, enhance their skills, and smoothly transition into industry jobs after graduation.

CDIO IMPLEMENTATION IN THEFIRMA

Bachelor of Engineering students have 240 ECTS degree program, where the curricula consist of 210 ECTS core competence studies and 30 ECTS optional studies. The core competence studies consist of 75 ECTS basic studies, 90 ECTS professional studies, 30 ECTS practical training and 15 ECTS bachelor thesis. Bachelor of Business Administration students have 210

ECTS degree program with otherwise similar structure, but with 60 ECTS professional studies instead of 90 ECTS. Basic studies of each degree program are the same for all in same degree program. Professional studies are dependent on the competence track that students choose at the end of their first year. Table 1 describes the professional studies of engineering students in Software Engineering and Project Management -competence track.

Table 1. Professional studies of engineering students in Software Engineering and Project Management -competence track

Module name	Course name	Scope	Timing
Introduction to Software Engineering	Introduction to ICT Projects	10 ECTS	2nd year fall
	Introduction to Web Development	5 ECTS	
Software Development	Project Management	5 ECTS	2nd year spring
	Object-Oriented Programming with Python	5 ECTS	
	Back-end Development	5 ECTS	
Full Stack Development	Software Engineering and Modelling	5 ECTS	3rd year fall
	Advanced UI and UX design	5 ECTS	
	Front-end Development	5 ECTS	
Project Skills and Entrepreneurship	Innovation project	10 ECTS	3rd year spring
	Statistics and Probability	5 ECTS	
Software Business	ICT Projects	10 ECTS	3rd year spring
	Technical Sales	5 ECTS	
Software Engineering Practices	Mobile Application Development	5 ECTS	4th year fall
	Advanced ICT Projects	10 ECTS	4th year

During the Introduction to ICT Projects -course students complete 3 ECTS (81 hours) of project work and 7 ECTS of theory and assignments related to theory. During the ICT Projects -course students complete 4 ECTS (108 hours) of project work and 6 ECTS of theory and assignments related to theory. During the Advanced ICT Projects -course students complete 5 ECTS (135 hours) of project work and 5 ECTS of assignments. In addition to these courses, students can complete up to 30 ECTS of project work as internships, 30 ECTS of project work as optional studies and 15 ECTS as their thesis at theFIRMA. Thus, students can complete up to 87 ECTS by working in theFIRMA projects.

TheFIRMA operates throughout the year. In the beginning of academic year in September roughly 120-130 students participate theFIRMA projects. Half of the students are second year students just entering to the competence track and to theFIRMA. Half of the students are fourth year students, that have already done a lot of project work at theFIRMA. Students apply for three most interesting projects and fill in the application and skill profile in Project Gate, which is a custom-made in-house software done by theFIRMA for handling the projects and resources. Usually, project teams are composed in a way, that there are junior and senior level students in the same project. Thus, senior level students can mentor junior level students while they are learning new skills and technologies.

In the beginning of spring semester, fourth year students continue with the projects where they have been working in the fall semester or if the project is finished, they will apply to new projects. Second year students have finished their projects – or at least their part within the projects by the end of fall semester. Third year students start their course and apply to projects as well. New project groups are composed based on the student's applications.

Spring semester ends in the end of April. After that, students mainly do internships in theFIRMA. The application process follows the same structure than in any company. Students interested in doing internship at theFIRMA apply with application and CV. Student CEO and Vice CEO interview all the applicants and choose together with TUAS staff members suitable interns. Usually, students work full-time at theFIRMA from April to mid of August, completing one or two internships, each lasting 7 weeks.

TheFIRMA’s project workflow is deeply rooted in the CDIO process, which encompasses conceiving, designing, implementing, and operating solutions for industry partners. This workflow begins with initial discussions to identify client needs and define project goals. Collaborative planning follows, involving students, TUAS staff members, and industry representatives to ensure a comprehensive project design. TheFIRMA sends an offer for the potential client that describes the project in detail, schedule and price. Once a project is initiated, students work in teams to execute their plans using project management methodologies suited to the project’s scope, such as agile or waterfall approaches. Finally, the operational phase ensures the delivery of final solutions to the client, often accompanied by post-project support and evaluation.

This systematic approach is further reinforced by adherence to CDIO Standards. Integrated Curriculum ensures that projects are embedded into students’ academic programs, allowing them to earn credits while gaining practical experience. Engineering Workspaces provide students with a professional environment conducive to teamwork and client interactions. Integrated Learning Experiences merge technical and interpersonal skills development, aligning with the demands of real-world engineering projects. Active Learning emphasizes student ownership of their educational journey through activities such as self-assessment, peer feedback, and direct client engagement. The impact of these implementations is significant. Students develop enhanced employability skills, often securing roles in local and

international companies. For industry partners, theFIRMA offers cost-effective solutions while creating opportunities to engage with and mentor emerging talent. Figure 1 presents part of theFIRMA staff and students in 2024.



Figure 10. TheFIRMA staff and students

LESSONS LEARNED

Looking back, in the beginning there were a few dozen students working in theFIRMA. Nowadays, more than 200 students are working in theFIRMA on a yearly basis. Some might be working only 80 hours and others might be working several hundred hours. Once the students gain enough experience, they usually find jobs in the IT field. This is great because it aligns with the primary goal of theFIRMA. However, at the same time, it also presents a significant challenge in managing projects due to the constantly changing resources.

Students have a dedicated office, where they can cooperate in projects, ask for help when needed, hangout, network with fellow students, and do homework. The office space has become the heart of theFIRMA, aligning with CDIO standard 6, Engineering Learning Workspaces, which emphasizes the importance of a physical learning environment. However, students provided feedback that it was challenging to find common working times with peers from different cohorts. To address this, we allocated dedicated time slots in the schedules of students in the SEPM competence track. These designated time slots allow students to gather at theFIRMA's office and collaborate on their projects more effectively.

In addition, theFIRMA arranges several different kinds of events for the students. Bread and Games is arranged a few times per semester, during which students can freely play together with digital and board games. Tech-club is arranged twice a month. In this event, volunteering students teach peers about software, project management or technical topics that they have

learned and found useful in their project work. These events foster a sense of community among students, encouraging collaboration, knowledge sharing, and peer support, which are essential elements for maintaining an engaging and inclusive learning environment.

Standard 6 also emphasizes the importance of a digital learning environment that leverages digital technologies to enhance both the student learning experience and teaching effectiveness. While theFIRMA has made progress in developing its digital learning technologies, there remains room for further improvement to fully optimize these tools and support evolving educational needs. In previous years, students were applying to projects using Microsoft Forms. It became evident that theFIRMA needed more efficient way to handle the applications as the number of students – and applications – was rising. Starting from fall 2023, students apply for their three most interesting projects and fill in the application and skill profile using Project Gate, which is a custom-made in-house software developed by theFIRMA for handling the projects and resources.

Currently, students fill in self- and peer assessment forms in Microsoft Forms. Additionally, students return project working hours in Excel sheet on a weekly basis in theFIRMA Itslearning workspace. Handling the self- and peer assessments and weekly working hour submissions require a significant amount of manual work. To alleviate this problem, we are now developing Project Gate 2.0, which will automate the assessment processing and working hour tracking.

TheFIRMA applies CDIO standard 7: Integrated Learning Experiences by combining technical knowledge with personal and interpersonal skill development through real-world projects. Students work in multicultural teams to design and implement solutions while considering social, economic, and environmental impacts. Collaboration with industry partners ensures practical experience and supports professional growth. Curriculum design ensures that second-year students can build foundational skills through accessible learning experiences, while gradually progressing to more demanding projects alongside senior students – fostering peer learning and collaboration across cohorts and supporting individual study paths.

CDIO standard 8: Active Learning is being adopted to theFIRMA by incorporating experiential and hands-on learning methods through client-based projects. Students actively engage in problem-solving, designing, and implementing real-world solutions. This approach not only enhances personal and interpersonal skills but also fosters critical thinking, self-reflection, and lifelong learning habits. Regular feedback and collaboration further support students in applying their knowledge to new contexts and challenges.

TheFIRMA follows a structured project process applied to all projects. Each team prepares key documents, including a kickoff form, project plan, final report, and closing summary. Learning goals are set at the start and reflected upon at the end. For ongoing projects, a handover document replaces the final report to support continuity between teams. Students also complete self and peer assessments, while customer feedback is gathered during and after the project.

CONCLUSIONS AND FUTURE WORK

As theFIRMA enters its second decade, it focusses on several key areas. These include expanding international collaborations to expose students to global engineering practices, enhancing digital tools for project management and assessment, and developing long-term partnerships with industry to co-create educational content and research opportunities.

TheFIRMA exemplifies how the CDIO framework can be effectively implemented to foster industry collaboration in engineering education. Over the past decade, theFIRMA has evolved into a vibrant learning environment that not only enriches student learning but also contributes to regional economic development. By combining hands-on projects with theoretical learning, it equips students with technical expertise and professional skills, ensuring their readiness for the workforce.

Looking forward, there is a need to further streamline digital workflows and improve automation in project management and student assessment processes. Plans for the development of Project Gate 2.0 aim to enhance data tracking, feedback collection, and resource allocation, supporting scalable growth and operational efficiency.

The leadership of theFIRMA has been rather light. TheFIRMA has two responsible teachers, student CEO, student vice CEO and QA team, that does the testing and auditing for the projects. Student CEO has been an active role from the beginning of launching theFIRMA and its usually one-year vacancy. Student CEO is typically in charge of handling the resources together with the teachers, meeting potential customers, drafting offers and other administrative work related to theFIRMA.

As the work of theFIRMA CEO has grown, the student vice CEO role was added five years ago. The student vice CEO oversees the Citizen's Helpdesk and assists the CEO where needed. From the fall of 2023 the Software Engineering and Project Management - competence track has had more than 200 students, significantly increasing the workload for both student CEO and student vice CEO. It has become evident that there is a need for more roles in theFIRMA management. Thus, the new role student Head of Operations (HOO) has been added. Student HOO is responsible for checking the weekly returned project working hours and for developing the quality process of theFIRMA in cooperation with TUAS staff members and theFIRMA QA team.

Additionally, strengthening ties with industry partners remains a priority to ensure projects remain relevant and aligned with current market needs. Efforts to introduce more advanced technologies and methodologies, such as AI-driven tools and data analytics platforms, will help theFIRMA maintain its competitive edge as a modern learning environment. Continued collaboration with SMEs is supported through active networking and outreach, aiming to build long-term, mutually beneficial partnerships.

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CDIO LEARNING SPACES IN DIGITAL TRANSFORMATION: A CASE AT VINH UNIVERSITY, VIETNAM

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ABSTRACT

In digital transformation, learning spaces are vital in enhancing education quality by creating environments that foster creativity, problem-solving skills, and hands-on experience for students. This study examines the implementation of CDIO-based education with a focus on Standard 6 - technical learning spaces, at Vinh University, Vietnam. Quantitative and qualitative methods were employed to collect data from students and faculty members. The findings indicate that while the university has made significant progress in modernising its learning spaces and integrating digital technology, there are still areas for improvement. The study concludes by proposing some solutions to improve the learning spaces to be aligned with CDIO standards and digital transformation in higher education.

KEY WORDS

Learning Spaces, Blended Learning, Digital Transformation, Standard: 6

INTRODUCTION

At every stage of education development, **technical learning space** plays a key role in improving the quality of training and developing comprehensive capacity for learners. Research by Radcliffe (2009) highlighted the importance of designing learning spaces in higher education, including classrooms, libraries and laboratories. With the development of the internet, the learning spaces include both physical and virtual environments. According to Bygstad (2022), the implementation of digital learning spaces in higher education involves three fundamental factors: 1) The alignment between digital education and digital subjects: This provides a solid technical foundation, making it easy for students to access and apply technology in learning; 2) Redefining the roles between teachers and students: Digital learning spaces allow for new and more intensive forms of learning, in which teachers play a supporting and guiding role, while students are active in acquiring knowledge and forming skills; 3) Transcending physical and institutional boundaries: These spaces enable universities to interact with the broader society, expanding the scope of education, and connecting with the community. In addition, the design of informal learning spaces in universities has also been shown to positively impact students' learning and social interaction. Physical spaces like building lobbies, corridors, and libraries are designed to encourage students to engage in self-directed learning, promoting interpersonal interaction and collaboration. In **digital transformation**, technical learning spaces are important in building and developing an advanced educational ecosystem where students can access modern technologies and develop essential skills for the digital era. Digital transformation in education is not only about applying technology but also about changing the approach to learning through restructuring **physical and digital learning spaces** to optimise the learning experience and develop learners' creative capacity. Modern technical learning spaces provide traditional facilities such as laboratories or workshops **and a digitised environment** where students can learn through **Virtual Reality (VR)**, **3D simulation** and interactive online learning tools. According to Dao (2019), virtual reality (VR), 3D simulation, and interactive online learning help students access knowledge more intuitively and immersively, creating an enriching and practical learning experience. Applying virtual reality and similar technologies to teaching helps improve practice and enhances students' ability to teach themselves, which is especially necessary in the digital transformation era (Tu et al., 2022). The investment and development of these spaces will bring long-term benefits to both learners and society. This paper reports a case study of CDIO implementation at Vinh university with a focus on standard 6 - technical learning spaces of the latest CDIO version 3.0.

LITERATURE REVIEW

The development of Standard 6 in CDIO Version 3.0

The CDIO initiative began from aeronautical engineering and the application of CDIO model has been still the most popular with the engineering discipline. In practice, the CDIO-based approach can be applied to other disciplines as it ensures a framework of knowledge and skills. Since its inception in the early 2000s, the CDIO initiative has been continuously improved to adapt to the changing educational and industrial environment. These improvements have greatly benefited the orientation of technical training, helping universities focus on theory and build academic programs focusing on practice and career skills development. After several versions, the current CDIO version 3.0 effectively supports the training of future engineers by developing a curriculum based on practical projects, promoting problem-solving and systems thinking. The improvements in the CDIO versions are intended

to align with the practical context and educational innovation requirements. The development of CDIO versions is shown in Table 1:

Table 1. Development of CDIO Syllabus Versions

CDIO Syllabus contents	CDIO Syllabus 1.0	CDIO Syllabus 2.0	CDIO Syllabus 2.0	CDIO Syllabus 3.0
1. Technical knowledge and reasoning	Basic Technical Knowledge	Extensive technical knowledge, including emerging fields	Translated and regionally adjusted content	Integrating advanced technology (AI, IoT)
2. Personal and professional skills and qualities	Personal and professional skills	Greater emphasis on lifelong learning and professional ethics	Focus on local vocational skills	Greater emphasis on innovation and entrepreneurship
3. Communication and teamwork skills	Teamwork and communication	Enhance communication in diverse environments	Emphasis on cultural diversity in teamwork	Global teamwork and interdisciplinary communication
4. Conceptualisation, design, implementation and operation of the system in the context of business and society	The CDIO Process in the Technical Context	Extended scope to include environmental and social impacts	Adapting the CDIO process for local businesses	Sustainability, ethics, and global impact in the CDIO process

The CDIO 3.0 set of standards (Malmqvist et al., 2020) consists of 12 closely related standards that form a framework for developing a comprehensive technical training program. These standards guide curriculum improvement, ensuring that students can develop the necessary professional skills in real-world technical environments. Of the 12 CDIO standards, Standard 6 – Technical learning spaces profoundly influences the design and construction of learning environments in modern technical training programs. For the CDIO 3.0 version, the learning spaces not only include engineering workspaces and traditional laboratories but also integrate a digital environment, such as online tools and spaces, virtual reality (VR) and 3D simulations that facilitate teaching and enhance learning effectiveness. These technologies allow students to practice safe simulation systems before performing on devices.

As Standard 6 is to create a flexible and interactive learning environment where students can develop skills through hands-on projects, it directly contributes to the implementation of Standard 5 on the design–implementation experience and Standard 7 on the integrated learning experience. Moreover, modern technical learning spaces also promote active learning methods, helping students promote creativity and problem-solving abilities, thereby meeting the practical requirements of the industry.

The construction of technical learning spaces also supports the capacity of lecturers, creating conditions for them to apply new teaching methods, thereby improving standards 9 and 10 on teaching capacity development. As a result, it makes a contribution to improving the quality of

teaching and the effectiveness of learning assessment of Standard 11 and program evaluation of Standard 12. Furthermore, the construction of appropriate technical learning spaces promotes the implementation of active learning methods of Standard 8, encouraging students to actively participate in the learning process and develop self-study skills. This improves the quality of training and prepares students to meet the increasing demands of modern industry.

The impact of digital transformation on the design of technical learning spaces

From the technical perspective, digital transformation is an organisation's shift to big data, analytics, cloud, mobile, and social media platforms (Vial, 2021). In education, integrating digital technologies such as virtual reality (VR), augmented reality (AR), and online learning platforms has opened up new educational methods, helping students access knowledge in an interactive and proactive way. For instance, using VR and AR in technical training allows students to experience real-life situations in a virtual environment, enhancing hands-on skills without any risk of virtual reality devices. Bygstad et al. (2022) analysed the transition from traditional learning methods to digital learning spaces, emphasising that digital transformation is not merely using technology but also changing how education is organised and managed. Wang and Liu (2021) also noted that digital learning spaces can promote multi-dimensional interaction and facilitate experiential learning activities. In Vietnam, Tran et al. (2022) have shown that using digital platforms such as Moodle and Microsoft Teams in online teaching improves teaching efficiency and expands educational access opportunities for students in remote areas. Regarding the design of learning spaces, Beichner (2014), with the SCALE-UP model, has proven that flexible learning spaces can effectively support positive learning methods, which enhances student participation in the classroom. Lin et al. (2019), who studied the application of virtual reality (VR) and augmented reality (AR) technologies in learning space design in Asia, concluded that these technologies not only enhance interactivity but also help improve learning outcomes.

To catch up with the trend, the Vietnamese government has developed a comprehensive digital transformation roadmap for 2025 with a vision for 2030 (Lam, 2021). Many policies have been introduced, and several major training programs on digital transformation have been implemented at different levels (Lam, ibid.), prioritising digital transformation in all fields, such as education and training, developing platforms to support remote teaching and learning, digitising documents, building online learning resources, etc. (Prime Minister, 2020); Ministry of Education and Training, 2022). There have also been documents guiding how to build digital learning materials and online courses on the application of the platform providing open online courses (Ministry of Education and Training, ibid.). Thus, digital transformation has significantly influenced the design of technical learning spaces in CDIO training in Vietnamese universities, which has created profound changes in the design of technical learning spaces towards a more flexible and efficient modern learning environment. Although there have been some studies on the design of learning spaces, there is still a lack of specific studies on combining the CDIO model and digital transformation in the design of learning spaces at Vietnam’s universities. This study aims to fill the gap by exploring the design of CDIO learning spaces in the context of digital transformation, focusing on the case of Vinh University.

METHODS

Data Collection

The primary data are collected from multiple sources, including survey questionnaires, interviews with stakeholders, reports of accreditation agencies, Vinh University’s annual

reports, and other related documents such as proceedings of institutional conferences and faculty workshops. Field observations of learning spaces such as laboratories, labs, libraries, and shared learning areas also provide additional information for the data analysis.

Research methods

This study employs a mixed research approach including quantitative and qualitative methods to address research issues related to the design of CDIO learning spaces in digital transformation at Vinh University. The quantitative method uses questionnaires to survey the satisfaction of Vinh University's learning space in four areas: learning areas and campus landscapes, library and learning material system, practice and experiment spaces, and learning spaces integrated with digital technology. The survey subjects include faculty and students at Vinh University. The research sample was selected using a stratified random selection method, ensuring the representation of different academic disciplines. Three hundred students and 50 faculty members participated in the quantitative survey, while 20 people from these groups were selected for in-depth interviews.

Evaluation and benchmarking

The results of data analysis are evaluated and benchmarked against CDIO version 3.0 standards with a focus on Standard 6 - technical learning spaces. This comparison aims to determine the level of response of Vinh University to the requirements of the CDIO and to make appropriate proposals for improvement.

FINDINGS AND DISCUSSION

CDIO implementation at Vinh University

Vinh University, one of the leading multidisciplinary universities in Vietnam, has officially implemented the CDIO-based undergraduate programs since 2017. Applying the 12 CDIO standards promotes fundamental innovation in training development and contributes to shaping the modern training approach, meeting the requirements of the Vietnam National Qualifications Framework. The CDIO training programs at Vinh University are designed to comprehensively develop students' knowledge, skills, attitudes, practical competencies and sense of social responsibility (Vinh University reports, 2022, 2023, 2024).

Based on the 12 CDIO standards, Vinh University has flexibly adjusted and implemented the specifics of the industry and the local context. Unlike institutions that only apply CDIO for engineering programs, Vinh University has expanded the scope of application to non-technical disciplines such as journalism, social work, and teacher training. The implementation of CDIO at the university is built on a foundation of active learning, encouraging students to participate deeply in the learning process through advanced methods such as project-based, flipped, and blended learning. Moreover, the university has applied digital technologies to design learning spaces, creating favourable conditions for students to optimally develop their creativity and self-learning skills.

Learning spaces at Vinh University

In order to meet the Standard 6 of CDIO 3.0, Vinh University has built modern, flexible and diverse learning spaces which include physical and virtual components. The facilities are designed to provide maximum support for teaching, research, learning and practical activities.

Physically, the university boasts two large campuses in addition to three practical premises with a total land area of over 120 hectares. The practice and experiment complex consists of 50 modern laboratories, fully equipped with advanced equipment and regularly upgraded to suit the CDIO-based training model. The library and learning resources center, the most extensive library in the North Central region, is equiped with modern facilities as well as printed and digital materials, which meets the training requirements of CDIO standards. Students can access international databases such as the Proquest Center and other digital platforms for online research and learning. Furthermore, the institution is affiliated with industry and the world of work to form a diverse learning ecosystem, which includes businesses, enterprises, and agencies, where students have the opportunity to do practicum and internship. It also has a network of 62 satellite schools for teacher training programs. The extended learning spaces help students comprehensively develop professional knowledge and skills.

Regarding learning spaces integrated with digital technology, the university has a good information technology infrastructure system to meet the needs of teaching, studying and research. The intranet system connects 15 buildings through five major transmission lines, providing high speed Gbps connection for more than 1,000 computers. In addition, the institution has installed over 250 wifi access points in key areas such as classrooms, laboratories, playgrounds, training grounds and dormitories, ensuring free internet access services for faculty and students.

To facilitate students learning, Vinh University adopts blended learning model, which comprises face-to-face classes and virtual lessons through online Learning Management System (LMS), and real-time virtual classes via Zoom, and Microsoft Teams platforms. E-learning materials are developed by the Center for Learning Resources Production equiped with modern facilities. At present, the university boasts over 20,000 e-lectures, providing abundant resources for online training programs. Since 2018, the university has adopted a blended learning model across all disciplines and types of training, in which at least 30% of the learning time and contents are flexibly implemented through the LMS system. The system integrates e-learning materials and video-recorded lectures according to appropriate scenarios and allows online formative assessment activities to keep track of students' learning. The practical application of modern technologies has helped the institution build a flexible digital learning environment, optimise learners' learning experience and improve training quality. The university also develops virtual laboratories and virtual research models, which provides students with simulated exercises and practice.

Evaluation of Vinh University's learning spaces

Faculty and students' evaluation

The faculty and students' satisfaction with the learning area and campus landscape is shown in Figure 2:

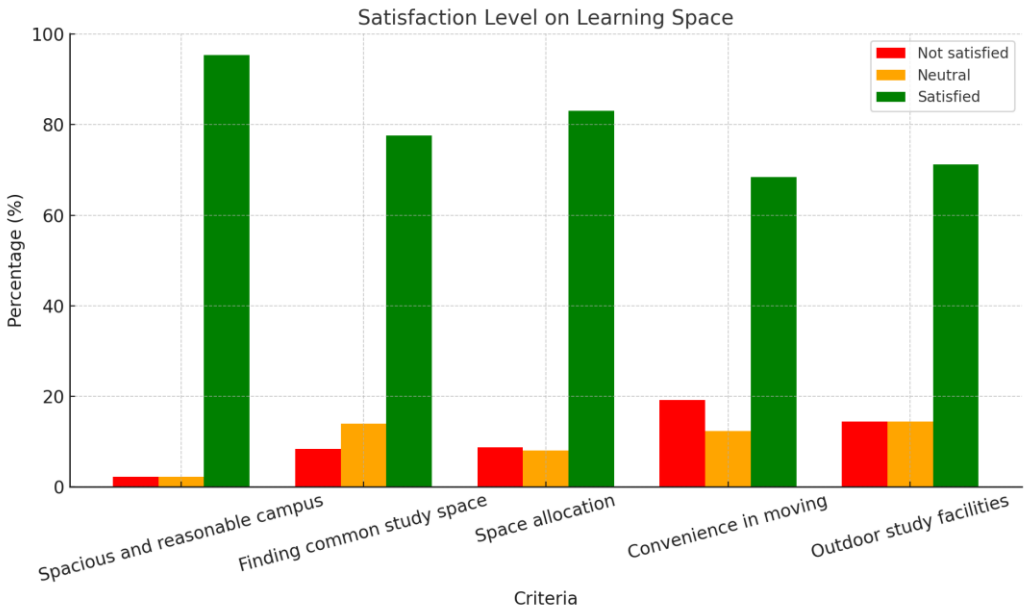


Figure 2. Student and faculty satisfaction with learning area and campus landscape

The bar chart indicates a generally high level of satisfaction among students and faculty concerning campus learning spaces, as evidenced by the predominance of green bars representing positive responses across most evaluated criteria. Notably, the “Spacious and reasonable campus” criterion yielded an overwhelmingly positive response rate, approaching 100%, which suggests a strong consensus on the adequacy and quality of the overall campus layout. However, the relatively prominent appearance of red (dissatisfied) and orange (neutral) responses in items such as “Convenience in moving” and “Outdoor study facilities” highlights challenges in spatial usability. The color distribution underscores the necessity for targeted improvements in spatial accessibility and the adaptability of learning environments. Such enhancements are essential to optimizing the pedagogical experience and aligning with educational philosophy.

For the library and learning materials system, the level of student and faculty satisfaction with the library and the learning material system is shown in Figure 3, which represents two columns for "Satisfied" (green) and "Dissatisfied" (red) levels in terms of criteria related to academic materials and libraries, making it clear to visualise the differences between assessments.



Figure 3. Student and faculty's satisfaction with the library and learning materials

As indicated in the bar chart, satisfaction is the highest for the diversity of learning materials (77.8%) and library facilities (79.1%) with minimal dissatisfaction. In contrast, respondents showed lower levels of satisfaction for "support in finding resources" (63.1%) and "library operating hours" (61.1%). The dissatisfaction rates of these two services are higher than other aspects, accounting for 31.2% and 25.3%, respectively. Digital materials accessibility is also a concern, where the dissatisfaction rate accounts for 29.5%.

With reference to practice and laboratory spaces, the levels of satisfaction of students and lecturers are quite high as indicated in Figure 4 below:

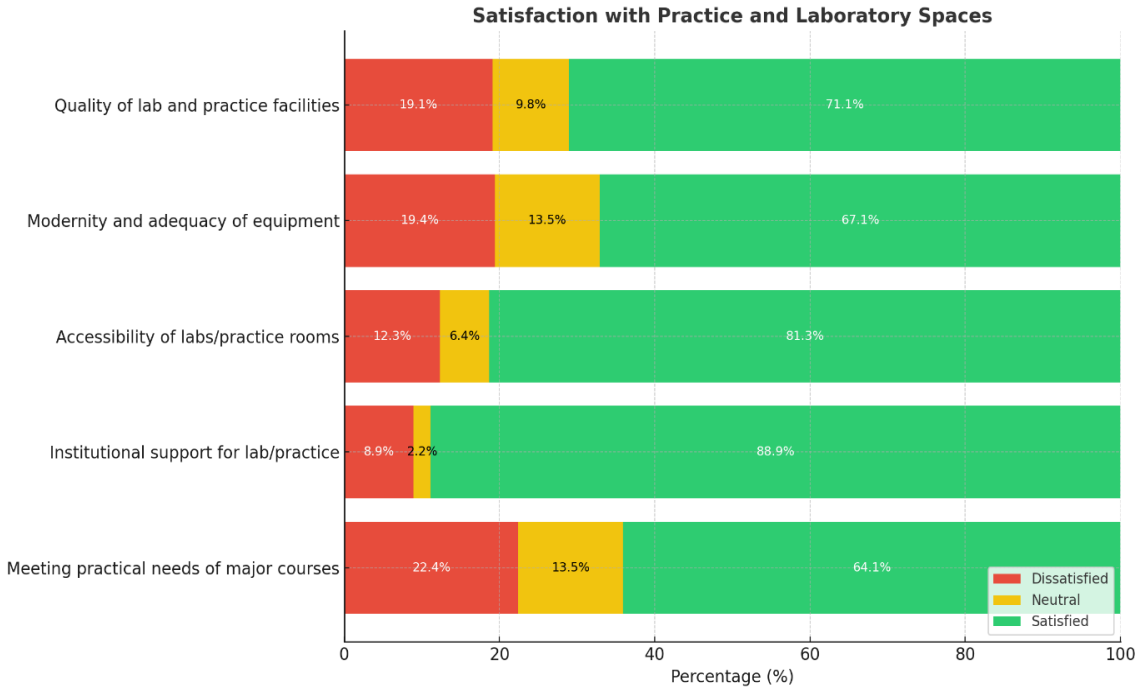


Figure 4. Students and faculty's satisfaction with practice and laboratory spaces

The chart shows a generally high level of satisfaction regarding access to practice and laboratory spaces, particularly in criteria such as “institutional support for lab activities” (88.9%) and “access to labs/practice rooms when needed” (81.3%), as reflected in the dominance of green bars. However, other criteria such as “modernity and adequacy of equipment” (67.1%) and “meeting practical needs of major courses” (64.1%) received slightly lower satisfaction rates and a more noticeable portion of neutral and dissatisfied responses. This indicates that while the overall infrastructure supports hands-on learning, certain departments or specialized fields may still face challenges related to equipment quality and resource availability. These gaps highlight the importance of further investment in both physical and virtual lab environments to enhance practical learning experiences, particularly in technology- and engineering-intensive disciplines.

For learning space integrated with digital technology, the level of satisfaction of students and lecturers with the digital technology-integrated learning space is shown in Figure 5. The different colours represent the three levels of satisfaction: "Not Satisfied", "Not Very Sure", and "Satisfied", helping to visualise the distribution of the percentages of each criterion as a whole.

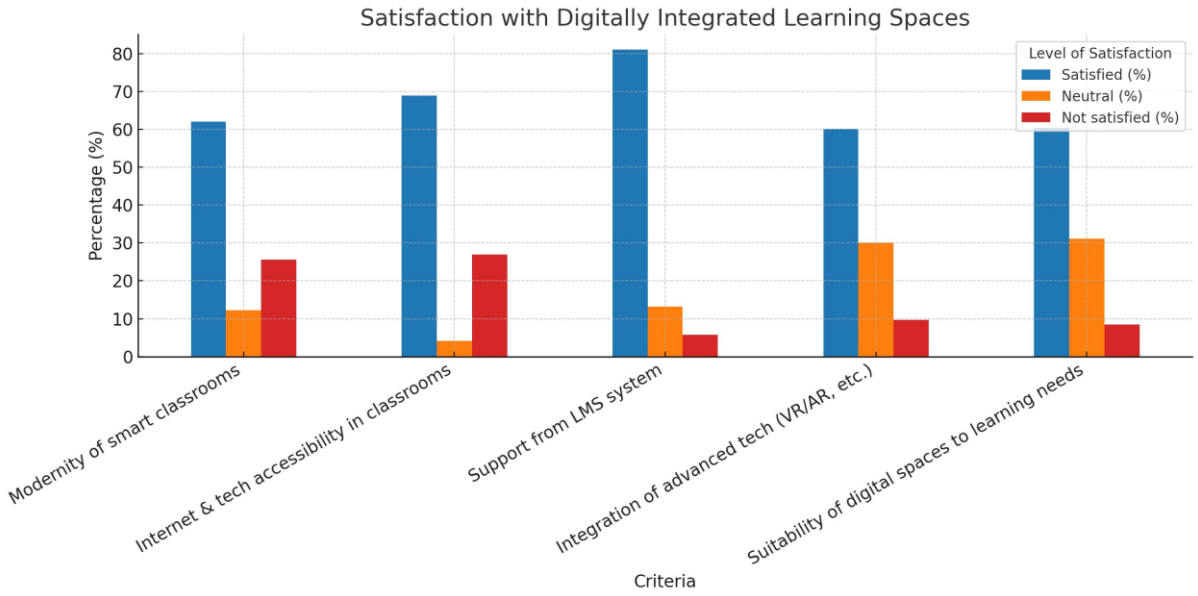


Figure 5. Satisfaction of students and lecturers with digital learning spaces

The survey results on the satisfaction of students and lecturers with the digital technology-integrated learning space reflect the institution’s efforts in digital transformation, and also point out the limitations that need to be overcome. The modernity and comfort of smart classrooms reached a satisfaction level of 62.1%. However, there were still 25.6% dissatisfaction, indicating the need to invest more in facilities. The ability to connect to the internet and use technology in classrooms received 68.9% satisfaction and 27% dissatisfaction, showing that the internet and technology accessibility in some areas of the university needs to be improved. It should be noted that online learning management systems (LMS) gained the highest ratings, with 81.1% satisfied and only 5.7% dissatisfied, reflecting the effectiveness of learning and teaching support. Nonetheless, integrating modern technologies such as VR/AR and specialised software in teaching received only 60.2% satisfaction, 9.7% dissatisfaction and 30.1% neutral opinion, revealing that the university needs to increase the application of advanced technologies to improve the teaching experience. The suitability of the digital

learning spaces with learning needs gained 60.4% satisfaction while the dissatisfaction rate was 8.5%, and the neutral responses accounted for 31.1%, which set the adjustment requirement so that the digital learning space is more closely associated with the actual needs of students and lecturers. In short, although the university's digital technology system has notable strengths, such as the effectiveness of LMS, there are still limitations in infrastructure and integration of modern technology. Improvement of these factors will help enhance the student experience and more comprehensively promote digital transformation in education.

In addition to the survey results mentioned above, the in-depth interviews with 20 lecturers and students provided further information about the university's digital learning resources and spaces. Most of the interviewees commented that although the university campus is spacious, it has not been optimally designed to serve students' experiential learning activities. Common learning spaces for students, such as self-study areas or group discussions are insufficient for students's demands, especially at peak hours and at the end of semesters when they intensively prepare for their final exams and assignments. Access to digital resources on the LMS is generally readily available; however, it is sometimes hard for students to download online materials when they study at campus 2, where the internet connectivity is not as strong as it is at the main campus. The e-lectures serve as pre-class resources which students have to work on before face-to-face interaction in the classroom; the accompanied tasks and activities have not met students' expectations. In e-lectures, each chapter is usually followed by a multiple-choice test and students are expected to achieved at least 70% correct answers to make sure that they have grasped the lesson contents. Our interviews indicated that the students expect to be guided by a virtual teacher (AI assistance) when they are unable to fulfill the end-of-chapter tasks. Interviews with faculty reveal that a majority of them need training in AI application for developing digital materials. The faculty also stressed the importance of upgrading the university's digital learning spaces as specified in Standard 6 of the CDIO version 3.0.

Thus, the results of the in-depth interviews with faculty and students concur with the previously collected survey data. The qualitative responses reflected the same key issues identified in the quantitative analysis, including the lack of optimized spatial planning, limitations in laboratory equipment, and the urgent need to invest in digital learning resources and technology-integrated spaces. Positive assessments of the library and the LMS system were also reaffirmed, highlighting existing strengths that should be further promoted. This consistency between qualitative and quantitative data provides an overall picture of the current state of learning spaces at the university, based on which some suggestions for improvements are made in the following section.

Benchmarking against CDIO Standard 6

Standard 6 of CDIO 3.0 defines engineering learning workspaces as a physical learning environment that includes engineering workspaces and laboratories that support and encourage hands-on learning of product, process, system, and service building, disciplinary knowledge, and social learning, combined with a digital learning environment that includes on-line tools and spaces that support and enhance the quality of teaching and student learning. There are six levels of achievement (0-5) indicated in Table 2 below.

Table 2. CDIO Standard 6 rubrics for self-assessment (https://cdio.org/content/cdio-standards-30)

CDIO Level	Criteria Description	Self-assessment
0	Technical learning spaces are insufficient or unsuitable for supporting practical skills, knowledge, and digital social learning.	Not applicable
1	The need for technical learning spaces to support digital, practical, and knowledge-based activities has been recognised, and a process to address this need has been initiated.	Achieved
2	Internal groups, including stakeholders, evaluate workspaces' functionality and teaching purpose.	Achieved
3	Plans for developing technical learning spaces are being implemented, and some new or renovated spaces are being utilised.	Achieved
4	Technical learning spaces fully support all digital, practical, knowledge, and skill learning components.	Achieved
5	Evaluation groups regularly review the impact and effectiveness of workspaces on learning and make recommendations for improvements.	Not achieved

The results of the survey and interviews indicate that Vinh university has significantly invested in renovating and developing technical learning spaces to meet the teaching and learning needs. The university's learning spaces such as laboratories, practice facilities, and virtual spaces have quite well support the students' development of knowledge and skills. Benchmarked against the rubrics in Table 3 above, the university has met the basic requirements of level 4 when the learning spaces have been able to comprehensively support technical training activities. Nonethless, there are certain aspects that need improving.

DISCUSSION AND CONCLUSIONS

Discussion

The survey and interviews show that the learning spaces at Vinh University have been positively evaluated in many aspects, in which the digitally integrated space is a highlight of the university's blended learning model. The university requires that the teaching process be divided into three phases: pre-class, during class, and post-class. In the pre-class phase, students learn on the LMS, which provides them with e-lectures, related activities and assessment. The expected learning outcomes of this stage are level 1 and 2 of the Bloom scale, which means remembering and understanding. The second phase is devoted to face-to-face interaction with lecturers and peers. The expected learning outcomes for this stage are levels 3 and 4 of Bloom's taxonomy, which corresponds to application and analysis. In the post-class stage, students review the lessons, do practice and perform experiments or implement their projects. The expected learning outcomes of this phase can be at levels 3, 4, and 5 (creating). The study indicated that the e-learning system with video taped lectures and

corresponding online activities has significantly facilitated students' active learning and self-study before face-to-face classes. Thanks to their prior self-study with LMS, students have more time for in-person group work, discussion, and practice in class.

The findings, however, also reveal that there is some room for improvement in planning, facilities and digital technology integration. Synchronous solutions are needed to meet students and lecturers' expectations. First, integrating modern technologies such as VR/AR and simulation software into the practice space will enhance the learning experience. This helps students gain a deeper understanding of the concepts and better prepares them for the requirements of the modern labour market. Second, developing digital learning spaces to support digital transformation in learning with priority on enhancing high-speed internet connectivity and deploying smart learning devices. In addition, the university needs to expand the application of advanced technologies such as VR/AR, simulation systems and interactive tools. These technologies provide an enriching learning experience and help align the teaching content with the actual needs of students. AI application to develop e-lectures should also be encouraged to facilitate students' pre-class learning activities. Technically, online learning management systems (LMS) must also be upgraded to support the personalisation of learning pathways and enhance interaction between faculty and students. This will create a more flexible and effective learning environment. Finally, it is necessary to develop an integrated learning space with physical and digital components that maximise students' potentials and support the blended learning model.

Conclusions

The paper analysed the current status of the learning spaces at Vinh University based on the CDIO model in the context of digital transformation. The research points out strengths and identifies limitations of CDIO-based application at the institution, thereby proposing specific solutions to optimise the design and development of learning spaces. The findings indicate that the application of the CDIO model with digital learning space design has been proven to be appropriate and effective in integrating technical, practical and innovative elements into the training process. At the same time, digital transformation has facilitated the application of advanced technologies such as VR/AR, online learning systems (LMS), and digital materials, opening up opportunities to enhance the learning and teaching experience. The research findings also imply that it is essential to improve not only the digital learning spaces, but also the quality of digital learning resources to enhance students' CDIO experiences.

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BRIDGING TECHNICAL AND LEADERSHIP COMPETENCIES: INTEGRATING CDIO WITH THE SUSI YWLP

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ABSTRACT

This paper explores the integration of leadership training into engineering education, addressing the increasing need for engineers to possess both technical expertise and effective leadership skills in today's complex world. It proposes the CDIO (Conceive-Design-Implement-Operate) framework as a robust approach to achieving this integration. The CDIO framework, with its emphasis on hands-on learning, teamwork, and project management, equips students with essential soft skills alongside their technical knowledge. This paper argues that combining CDIO with initiatives like the Study of the U.S. Institutes (SUSI) Young Women Leaders Program (YWLP) can particularly benefit female engineering students. The SUSI YWLP empowers young women with the leadership skills and confidence necessary to excel in various fields, including engineering. By integrating CDIO and SUSI YWLP, female students gain a unique opportunity to develop technical proficiency and leadership potential, effectively preparing them for the challenges they face in a field where women are often underrepresented. The paper highlights these challenges, such as the lack of visible role models and limited leadership opportunities, and emphasizes the importance of mentorship, networking, and creating inclusive environments. This integration of CDIO and the SUSI YWLP offers a comprehensive approach to fostering leadership development among female engineering students. It provides a synergistic framework that combines CDIO's practical, project-based learning with the SUSI YWLP's focus on empowering women leaders. This approach not only cultivates essential leadership skills but also addresses the specific obstacles women encounter in engineering education and the profession. Ultimately, this paper contributes a theoretical foundation for future research and practice, paving the way for a more inclusive and effective model of engineering education that equips all students, particularly women, with the leadership skills needed to drive innovation and succeed in their careers.

KEYWORDS

CDIO, SUSI YWLP, Women in Engineering, Leadership Development, Theoretical Framework, Conceptual Framework, CDIO Standard 4

INTRODUCTION

In the dynamic and fast-evolving field of engineering, technical expertise alone is insufficient to tackle the complexities of modern challenges. Engineers must also develop strong leadership skills to guide interdisciplinary teams, innovate solutions, and manage projects effectively. The increasing complexity of engineering projects demands that engineers possess not only technical proficiency but also the ability to collaborate, communicate, and lead diverse teams (Paul & Falls, 2015). This necessity is further emphasized by the evolving demands of the industry, which increasingly seeks engineers who can effectively manage projects and lead teams, highlighting the critical role of leadership capabilities in the engineering profession (Miska et al., 2022).

However, within the engineering profession, there is a significant underrepresentation of women in leadership positions. This disparity is not simply a matter of numbers; it reflects systemic challenges that hinder women's advancement in engineering. These challenges include the lack of visible role models, gender bias in the workplace, and limited access to mentorship and networking opportunities. Research indicates that women in engineering often feel isolated and unsupported, which can impede their professional growth and aspirations for leadership (Schmitt, 2021; Mullet et al., 2017). For instance, Mullet et al. (2017) highlight that social identities play a crucial role in women's success in STEM fields, noting that women, particularly women of color, may not see themselves as part of the engineering community due to a lack of relatable role models.

While the importance of leadership development for all engineers is recognized, there is a lack of a cohesive theoretical framework that specifically addresses the unique challenges and needs of women in engineering leadership development.

Addressing this gap is of paramount importance for several reasons. A strong theoretical framework for understanding women's leadership development in engineering is essential to guide the design and implementation of effective educational programs and interventions. It can also help organizations create more inclusive and equitable workplaces, fostering a culture where women can thrive and contribute their full potential. Furthermore, empowering women to assume leadership roles in engineering can drive innovation and enhance problem-solving by bringing diverse perspectives to the forefront (Eagly & Carli, 2003).

To address this gap, this paper proposes a novel conceptual framework that utilizes the CDIO (Conceive, Design, Implement, Operate) framework as a structural foundation, incorporating the leadership development strategies of the SUSI (Study of the U.S. Institutes) Young Women Leaders Program (YWLP). The CDIO framework offers a structured approach to engineering education that emphasizes hands-on learning and the development of both technical and leadership skills (Borrego & Bernhard, 2011). The SUSI Young Women Leaders Program provides targeted leadership training and mentorship opportunities specifically designed to empower women. This paper contributes to the theoretical understanding of how these two approaches can be combined to foster women's leadership development in engineering.

The remainder of the paper is structured as follows: Section 2 provides an overview of the CDIO framework and the SUSI Young Women Leaders Program. Section 3 details the proposed conceptual framework, explaining how the two approaches can be integrated. Section 4 discusses the potential benefits of this integration for women's leadership development in engineering. Finally, Section 5 concludes the paper and outlines directions for future research.

UNDERSTANDING THE CDIO FRAMEWORK AND SUSI YOUNG WOMEN LEADERS PROGRAM

This section provides an overview of the CDIO framework and the SUSI Young Women Leaders Program, highlighting their key components and relevance to leadership development, particularly for women in engineering.

The CDIO Framework

The CDIO framework is an educational model that emphasizes active learning through real-world projects, where students engage in the engineering lifecycle from conceiving and designing to implementing and operating solutions.

One of the primary advantages of the CDIO framework is its intentional development of managerial and leadership competencies among engineering students. Research indicates that incorporating teamwork and project-based learning, central to the CDIO framework, significantly enhances students' communication and leadership skills, which are crucial for their professional development (Salazar, 2024; Paul & Falls, 2015). The CDIO model fosters a collaborative environment that mirrors the dynamics of the engineering workplace by encouraging students to participate in real-world projects. This experiential learning is vital in preparing students to assume leadership roles, where they must effectively navigate complex team interactions and project management challenges (Bertoni & Bertoni, 2019; Miska et al., 2022).

The SUSI Young Women Leaders Program

The SUSI Young Women Leaders Program is a focused initiative designed to equip young women with the leadership skills necessary to excel in leadership roles across various fields, including engineering. The program fosters a global network of women leaders by providing leadership training, mentorship, and opportunities for personal and professional growth. Participants are encouraged to address social, political, and economic challenges, with a particular emphasis on leadership in areas where women are traditionally underrepresented, such as STEM.

The SUSI YWLP recognizes that the underrepresentation of women in engineering is significantly exacerbated by the lack of visible role models. Mullet et al. (2017) highlight that the absence of relatable role models can lead women, particularly women of color, to feel excluded from the engineering community and internalize the perception that they do not belong in these roles. This is further supported by research that highlights the prevalence of gender bias and discrimination within engineering workplaces, which can create hostile environments and limit women's opportunities for advancement (Catalyst, 2018). Additionally, the lack of family-friendly policies and support systems within engineering can disproportionately affect women, who often bear a greater share of caregiving responsibilities (National Academies of Sciences, Engineering, and Medicine, 2019).

A key component of the SUSI Young Women Leaders Program is its focus on mentorship and networking. Participants are paired with experienced female leaders who offer guidance, share career insights, and help students navigate the complexities of leadership. This mentorship is crucial for female engineering students, as it provides a model for how women can successfully balance technical careers with leadership responsibilities. As Pruitt et al. (2023) highlight, mentorship can provide valuable insights and support for women in academic leadership. Furthermore, research has shown that effective mentorship programs can

increase women's confidence, improve their career satisfaction, and enhance their likelihood of staying in engineering (NASEM, 2019).

The networking opportunities within SUSI also enable students to connect with other young women from diverse backgrounds, fostering a sense of solidarity and community. These connections are vital in a field where women often face isolation and underrepresentation. Chesler et al. underscore the effectiveness of same-gender peer mentoring in addressing the unique challenges faced by women faculty, providing crucial networking and support often lacking in male-dominated environments. This aligns with Schmitt's findings, which emphasize the vital role of social support in helping women engineers adapt to the engineering culture and advance into leadership positions (Schmitt, 2021). Initiatives like the Women's Initiative at various institutions aim to establish supportive networks that enhance the visibility and retention of women in engineering (Donohue & Vallas, n.d.). Moreover, professional organizations such as the Society of Women Engineers (SWE) play a critical role in providing networking opportunities, professional development resources, and advocacy for women in the field (SWE, n.d.)

CONCEPTUAL FRAMEWORK FOR CDIO AND THE SUSI YWLP INTEGRATION

This paper proposes a novel conceptual framework that integrates the CDIO framework, as a model for engineering education, with the leadership development curriculum and mentorship components of the SUSI Young Women Leaders Program (the SUSI YWLP). This integration aims to create a unique educational experience for female engineering students, addressing the underrepresentation of women in engineering leadership and enhancing their overall career potential. The framework is designed to synergize the strengths of both CDIO and the SUSI YWLP to foster a more holistic development of female engineering students.

Framework Overview

The proposed framework positions CDIO as the primary structural model for engineering education. CDIO's emphasis on the "Conceive, Design, Implement, and Operate" stages of real-world engineering projects provides a robust foundation for developing practical engineering skills (Borrego & Bernhard, 2011). This approach inherently fosters teamwork, project management, and problem-solving abilities, which are essential for future engineering leaders.

Integrated within this CDIO structure are key elements of the SUSI YWLP. Specifically, the framework incorporates the SUSI YWLP's targeted leadership development curriculum and mentorship components to address the specific challenges faced by women in engineering. The leadership curriculum provides focused training in areas such as strategic thinking, communication, and ethical decision-making, while the mentorship component offers guidance and support from experienced female leaders.

Core Components and Integration

The framework is composed of the following core components:

- **CDIO-Based Engineering Education:** This component provides the context for students' learning experiences. Students engage in CDIO projects that require them to apply engineering principles to solve real-world problems.

- **SUSI YWLP Leadership Development:** This component provides targeted leadership training that is integrated into the CDIO experience. For example, students may participate in leadership workshops as part of their CDIO projects or receive mentorship from female engineering leaders.
- **Mentorship and Networking:** This component, drawn from the SUSI YWLP, provides female students with access to mentors and networking opportunities. Mentors can provide guidance, support, and role modeling, while networking opportunities can help students build connections with other women in engineering.

Synergistic Effects

The integration of CDIO andthe SUSI YWLP creates several synergistic effects:

- **Enhanced Skill Development:** By combining CDIO's focus on technical skills with the SUSI YWLP's emphasis on leadership development, the framework equips students with a more comprehensive skill set that is highly valued by employers (Miska et al., 2022).
- **Increased Confidence and Empowerment:** The supportive environment and mentorship provided by the SUSI YWLP can help to increase female students' confidence and empower them to take on leadership roles (Schmitt, 2021).
- **Challenging Stereotypes:** By providing female students with opportunities to lead and succeed, the framework can help to challenge traditional stereotypes about women in engineering (Donohue & Vallas, n.d.).
- **Development of Role Models:** The framework supports the development of female students as role models, inspiring future generations to pursue STEM fields and leadership positions.

In summary, this framework leverages the structured, project-based learning of CDIO with the targeted leadership development and support of the SUSI YWLP to create a powerful educational experience for female engineering students.

POTENTIAL BENEFITS OF THE CONCEPTUAL FRAMEWORK

The integration of the CDIO framework and the SUSI Young Women Leaders Program offers several potential benefits for female engineering students, addressing key challenges they face and enhancing their leadership potential. This section outlines these benefits, focusing on empowerment, real-world leadership preparation, mentorship and networking, and the enhancement of long-term leadership potential.

Empowering Female Engineers through Leadership Integration

Within the CDIO framework, female students can develop essential leadership qualities through practical experience. For instance, leading project meetings, managing timelines and budgets, communicating with team members and stakeholders, and navigating conflicts provide invaluable opportunities to develop skills such as:

- Communication and Interpersonal Skills: Effectively conveying ideas, actively listening, and building strong relationships (Salazar, 2024).
- Decision-Making and Problem-Solving: Analyzing situations, evaluating options, and making timely, informed decisions (Bertoni & Bertoni, 2019).

- Teamwork and Collaboration: Fostering collaboration, delegating tasks, and motivating team members (Paul & Falls, 2015).
- Conflict Resolution: Identifying and addressing conflicts constructively to maintain a positive team dynamic.

The SUSI Young Women Leaders Program complements this by providing an additional layer of support and encouragement. The mentorship component of the SUSI YWLP, in particular, offers female engineering students valuable insights into navigating the challenges of leadership in male-dominated fields and developing a strong leadership presence (Pruitt et al., 2023). By participating in both initiatives, students gain a unique combination of technical expertise and leadership experience, better positioning them for future career success.

Real-World Leadership in Engineering

The synergy between CDIO's leadership-focused engineering curriculum and the SUSI YWLP's broader leadership training equips female engineering students to navigate the challenges of leadership in both technical and non-technical environments. This combination ensures that students not only gain the technical expertise needed to thrive in engineering but also develop the leadership mindset required to drive change, manage teams, and address global challenges.

The Role of Mentorship and Networking

A key component of the SUSI Young Women Leaders Program is its focus on mentorship and networking. Participants are paired with experienced female leaders who offer guidance, share career insights, and help students navigate the complexities of leadership. This mentorship is crucial for female engineering students, providing models for balancing technical careers with leadership responsibilities and offering support in overcoming gender biases (Chesler et al., n.d.).

The collaborative environment fostered by the CDIO framework further enhances these networking opportunities. By working in interdisciplinary teams, students practice leadership in diverse settings and interact with peers from a range of technical backgrounds, preparing them to lead diverse teams in their future careers.

Enhancing Long-Term Leadership Potential

The integration of CDIO and the SUSI YWLP enhances female engineering students' long-term leadership potential. Early exposure to leadership training increases the likelihood of women pursuing leadership roles (NASEM, 2019). By integrating leadership into the technical curriculum, CDIO prepares students for leadership roles from the outset, while SUSI helps build their self-confidence and leadership mindset. This integrated approach equips graduates with the technical skills, team management abilities, and understanding of organizational dynamics necessary for leadership positions in engineering. It also encourages them to mentor future generations of female engineers, contributing to a cycle of empowerment within the engineering community.

Future Research and Conclusion

This paper has presented a conceptual framework that integrates the CDIO framework with the SUSI Young Women Leaders Program, offering a theoretical approach to enhancing the leadership potential of female engineering students. The integration addresses the identified

gap in engineering education, where a lack of explicit leadership development, particularly for women, can hinder career advancement and perpetuate underrepresentation. By combining CDIO's emphasis on practical, project-based learning with the SUSI YWLP's focus on leadership skills, mentorship, and networking, this framework offers a synergistic model for fostering well-rounded engineering graduates.

Future Research Directions

This theoretical framework lays the groundwork for future research and practical implementation. Future research should focus on empirical validation of the framework's effectiveness. Specifically, studies could investigate the following:

- **Impact Assessment:** Quantitative and qualitative studies could assess the impact of implementing this integrated framework on female engineering students' leadership skills, self-efficacy, and career aspirations.
- **Comparative Studies:** Research could compare the outcomes of students who participate in the integrated program with those who participate in traditional engineering education or standalone leadership programs.
- **Longitudinal Studies:** Tracking the career trajectories of graduates from programs implementing this framework could provide valuable insights into its long-term impact on women's leadership in engineering.
- **Implementation Strategies:** Research is needed to develop effective strategies for implementing this framework in diverse institutional settings. This could include exploring optimal ways to integrate leadership modules into CDIO projects, recruit and train mentors, and create supportive learning communities.
- **Cross-Cultural Applicability:** Given the global nature of engineering, future research should examine the cross-cultural applicability of this framework and identify any necessary adaptations for different contexts.

Conclusion

Integrating the CDIO framework with the SUSI Young Women Leaders Program offers a promising approach to developing the leadership potential of female engineering students. This theoretical framework provides a foundation for future research and practical implementation, with the potential to contribute to a more inclusive, innovative, and effective engineering workforce. By equipping women with both technical expertise and leadership capabilities, this integrated model can help to break down barriers, drive change, and foster success in a globalized world.

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APPROACH TO DEVELOPING KEY COMPETENCIES FOR SUSTAINABILITY IN CHEMICAL ENGINEERING USING CDIO

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ABSTRACT

This paper shares the approach to integrating key competencies for sustainability in the context of chemical engineering using the CDIO Framework, with the aim of developing students' sustainability mindset, which is the key elements in one of the six graduate attributes from Singapore Polytechnic (SP) – namely ethics and responsible citizenry. The need is also consistent with the requirements of the Institution of Chemical Engineers, UK; that accredits the program. The paper outlines the approach developed in SP that provide guidance on how the development of sustainability mindset can be achieved. The SP approach involves the development of 8 key competencies for sustainability: interpersonal, intrapersonal, systems thinking, values thinking, futures thinking, strategic thinking, implementation thinking and integrated problem-solving. It allows each program to identify its own progressive pathway using applicable United Nation Sustainable Development Goals (UN SDGs) that leads to the development of integrated problem-solving competency from 7 other key competencies for sustainability. Each key competency for sustainability has a set of underpinning skills and attitudes mapped to the CDIO Syllabus. This paper then shows how the chemical engineering program uses this approach, providing examples of the program's coverage of relevant UN SDGs, and a map of where the 8 key competencies for sustainability are covered in the program modules. It then provides an example pathway of how systems thinking competency can be developed, that leads to the development of integrated problem-solving competency. The paper also discussed how the gaps identified in the existing curriculum can be closed.

KEYWORDS

Key Competencies for Sustainability, Chemical Engineering, CDIO Syllabus, CDIO Standards 2, 5, 7 and 12

Note: Singapore Polytechnic uses the word 'courses' to describe its education 'programs'. A 'course' in the Diploma in Chemical Engineering consists of many subjects that are termed 'modules'; which in the universities contexts are often called 'courses'. A teaching academic is known as a 'lecturer', which is often referred to a as 'faculty' in the universities.

INTRODUCTION

This paper covers the integration of sustainable development in the Diploma in Chemical Engineering (DCHE) program offered by Singapore Polytechnic (SP). It is an on-going continual improvement work from Yang et al (2023) and Oh et al (2024), taking reference from the work by Cheah et al (2025) that suggests an approach for programs in SP that seek to integrate key competencies for sustainability using the CDIO Framework, with the aim of developing sustainability mindset in SP students.

At SP, the 17 United Nations Sustainable Development Goals (UN SDGs) are used as the learning context to develop baseline emerging digital and human skills in students via the Common Core Curriculum (CCC) which comprises of 10 modules, compulsory for all SP students. These skills are integrated to the diploma curriculum via appropriate pairing with domain modules to serves as introductory competencies for students. These are to be further deepened or applied in the domain-specific contexts in core modules (Cheah, Lim and Chao, 2022).

The Institution of Chemical Engineers, UK (IChemE), selected UN SDGs 2, 3, 6, 7, 9, 12 and 13 as priority topics; along with areas considered as fundamental to chemical engineering, delivery of which supports the identified priority topics, as follows:

(1) Clean Energy and Climate Action (UNSDGs #7 & #13)
(2) Water and Sanitation (UN SDG #6)
(3) Food, Health and Well-being (UN SDGs #2 & #3)
(4) Responsible Production, Innovation and Industry (UN SDGs #9 & #12)
(5) Quality Education, including Lifelong Learning (UN SDG #4, which IChemE treat as cross-cutting requirements)
(6) Process Safety, including Major Hazards Management
(7) Digitalisation, including Cybersecurity

As the DCHE program is accredited by IChemE, we naturally follow the recommendations from IChemE to guide our integration of UN SDGs into the DCHE curriculum. This is a natural flow of our approach to redesign the DCHE curriculum, using the CDIO approach to integrate key competencies for sustainability, leveraging on prior work where various skills and attitudes required by job role of chemical engineers had already been integrated. The CDIO approach includes using selected UN SDGs challenges as learning context which are to be addressed using chemical engineering and product design, reviewing learning outcomes, proposing the development of key competencies for sustainability using integrated curriculum and active learning approaches, strengthening faculty competence and teaching competence for effective lesson delivery and facilitation. The aim of this paper is to showcase the approach of developing key competencies of sustainability in a diploma program. Hence, learning assessments and program evaluation will be done when the curriculum has been revamped.

APPROACH TOWARDS INTEGRATING KEY COMPETENCIES FOR SUSTAINABILITY

Since Academic Year 2022/2023, the CCC is integrated into the DCHE curriculum using a spiral curriculum model (Oh et al, 2024) by pairing CCC modules with domain modules. Prior to AY2022, sustainable development concepts are taught in the DCHE curriculum focusing mainly on chemical processes, plant design and chemical product design modules. DCHE had been integrating education for sustainable development (ESD) into its curriculum even before CCC was introduced (Cheah, 2021). With the introduction of CCC and integrated into the

DCHE curriculum, the DCHE Course Management Team (CMT) carried out a survey to review the coverage of sustainable development in the DCHE curriculum using UN SDGs as the guide (Yang et al, 2024). The purpose is to understand the coverage in DCHE modules that contextualize the UN SDGs to address complex engineering problems.

In this survey, the learning outcomes in each domain module are mapped to the 17 UN SDGs detailing the magnitude of coverage of whether a specific UN SDG is 'taught' and/or 'utilized' in each module. This approach primarily assessed the inclusion of UN SDGs within the DCHE curriculum but does not address the extent to which relevant skills are being developed.

This paper aims to develop key competencies for sustainability needed by DCHE graduates to develop their sustainability mindset using a generic approach outlined by Cheah et al (2025) for all programs in SP, adapted for DCHE. The approach builds on the foundation of DCHE curriculum that had integrated all the 10 mandatory CCC modules, There are 8 key competencies for sustainability – interpersonal, intrapersonal, systems thinking, values thinking, futures thinking, strategic thinking, implementation thinking and integrated problem-solving. This effort also serves to highlight the program's continual improvement effort in integrating sustainable development into its curriculum using CDIO Framework, as well as aligning the coverage of the UN SDGs with deepening of competencies in digital literacy, lifelong learning and process safety as desired by IChemE. The approach can be concisely summarized as follows:

1. Review one's existing program on coverage of relevant UN SDGs, i.e. which goal(s) is/are covered in which module(s), and the type of coverage – "teach" or "utilize"
2. For these modules (including CCC modules), identify key competencies for sustainability can are needed for achieving the aims of the chosen UN SDGs
3. Draft a pathway for developing the program's key competencies for sustainability to ensure it is appropriate for the specific program needs (Cheah et al, 2025), and progressively developed to the desired proficiency level. Suggested general guidance are as follows:
    - Proficiency at awareness level only can be confined within each module offered any semesters
    - Strengthen proficiency for modules offered in the same semester
    - Increasing proficiency for modules offered across different semesters
4. Use the Matrix of CDIO Syllabus vs Key Competency for Sustainability (see Appendix 1) that shows the underpinning skills and attitudes needed for each key competency; and hence identify any gaps in the requirements. For example, in a gap exists (i.e. the needed underpinning skills and/or attitudes are inadequate) then consider modify existing learning touchpoints (design-implement experiences, integrated learning experiences) or introduce new ones.
5. Review the applicable UN SDGs, to leverage on their mutual dependency where appropriate, e.g. UN SDGs #2 and #3, UNSDGs #7 and #13.
6. Review and revise the draft pathway as necessary and iterate to optimize the development process, strive to achieve a good balance of appropriate UN SDGs and key competencies for sustainability that matched the desired proficiency levels.

Table 6. Summary of UN SDGs Coverage in the DCHE Curriculum

United Nation Sustainable Development Goals	Teach	Utilize
#1 NO POVERTY End poverty in all its forms everywhere		
#2 ZERO HUNGER^ End hunger, achieve food security and improved nutrition and promote sustainable agriculture		
#3 GOOD HEALTH AND WELL-BEING^ Ensure healthy lives and promote well-being for all at all ages	✓	✓
#4 QUALITY EDUCATION Ensure inclusive and equitable quality education and promote lifelong opportunities for all		✓
#5 GENDER EQUALITY Achieve gender equality and empower all women and girls		
#6 CLEAN WATER AND SANITATION^ Ensure availability and sustainable management of water and sanitation for all	✓	✓✓
#7 AFFORDABLE AND CLEAN ENERGY^ Ensure access to affordable, reliable, sustainable and modern energy for all	✓✓	✓✓
#8 DECENT WORK AND ECONOMIC GROWTH Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all		
#9 INDUSTRY, INNOVATION AND INFRASTRUCTURE^ Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	✓	✓✓
#10 REDUCE INEQUALITY Reduce inequality within and among countries		
#11 SUSTAINABLE CITIES AND COMMUNITIES Make cities and human settlements inclusive, safe, resilient and sustainable		
#12 RESPONSIBLE CONSUMPTION AND PRODUCTION^ Ensure sustainable consumption and production patterns	✓✓✓	✓✓✓
#13 CLIMATE CHANGE^ Take urgent action to combat climate change and its impacts	✓✓	✓✓
#14 LIFE BELOW WATER Conserve and sustainably use the oceans, seas and marine resources for sustainable development	✓	✓
#15 LIFE ON LAND Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss		
#16 PEACE AND JUSTICE, STRONG INSTITUTIONS Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels		
#17 PARTNERSHIPS FOR THE GOALS Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development		

Legend: ^ indicates IChemE UK priority area
✓✓✓ indicates UN SDG is frequently used in the DCHE curriculum
✓✓ indicates UN SDG is moderately used to the DCHE curriculum
✓ indicates UN SDG is least frequently used in the DCHE curriculum

Coverage of Sustainable Development in DCHE Program

The DCHE curriculum consists of a range of learning touchpoints that develop aspects of some of the key competencies for sustainability such as systems thinking, interpersonal, implementation and integrative problem-solving competencies through chemical engineering domain modules, laboratory and process skills operation training, chemical product design and development projects, plant design projects, final year capstone projects and elective modules. From the survey, the 17 UN SDGs were mapped to the learning outcomes in each module with the purpose of understanding how extensively the UN SDGs were addressed in the disciplinary context (Step 1). The overall outcome of this mapping exercise is illustrated in Table 1.

From the survey, we also identified which modules can provide the best contexts for integrating the 7 key competencies for sustainability required to develop the integrated problem-solving competency using the SP approach to develop students' sustainability mindset (Cheah et al, 2025). These are then mapped against the modules in DCHE curriculum (Step 2) as shown in Table 2. It can be seen from Table 2 that the most well-covered and developed key competency for sustainability is that of interpersonal competency. This is hardly surprising as the DCHE curriculum always require students to working teams in all its learning activities. Likewise, implementation competency is also well developed from DCHE's project-related modules.

Table 2 revealed that systems thinking competency is mainly covered in project-based modules. From the perspective of chemical engineering discipline, systems thinking is one of the most important competencies traditionally covered in core topics such as process safety and loss prevention, in terms of making changes in process design or operations. Its importance can also be found in chemical product design and development, and its coverage in the DCHE curriculum can be enhanced.

Some aspects of futures thinking competency, values thinking competency, strategic thinking competency and intrapersonal competency were covered but they tend to be somewhat "scattered" among the various core modules. In particular, Cheah et al (2025) recommended that intrapersonal thinking, interpersonal, and values thinking competencies be developed earlier in the duration of studies to lay the foundation for other competencies namely systems thinking, futures thinking and strategic thinking. Some ideas for improving current coverage will be shared later.

Sample Development Pathway for Systems Thinking Competency

Traditionally the most important competency in chemical engineering from the safety perspective with regards to operation of complex chemical processing facilities is that of systems thinking. It is equally important in chemical product and development from the sustainable development perspective. Figure 1 illustrates an example pathway of how systems thinking competency can be developed (Step 3), building on the foundation of intrapersonal thinking, interpersonal, and values thinking competencies; which in turn are supported by generic competencies such as critical thinking, holding multiple perspectives, understanding of obligations of engineers to society and the environment, etc.

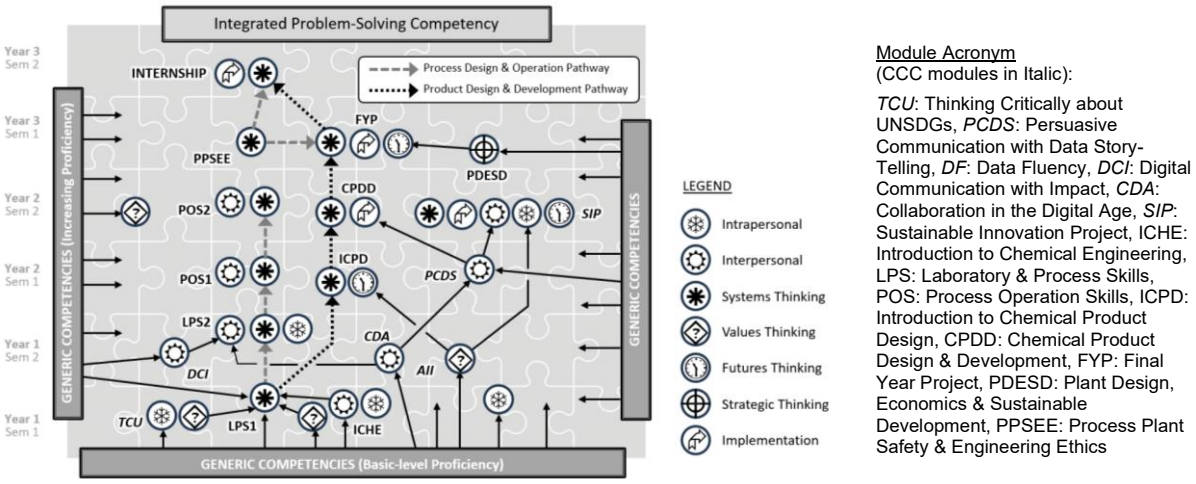


Figure 1. Possible Development Pathway for Systems Thinking Competency

Continual Improvement Plans

Steps (4), (5) and (6) provide the guidance to integrate other key competencies that support the development of systems thinking competency (Figure 1). Using Step 4, we can map out all the skills and attitudes covered in a program; which will help us narrow down the suitable modules that: (1) already have elements of underpinning skills and attitudes required for key competencies for sustainability integrated; or (2) provide suitable context(s) where such underpinning skills and attitudes can be integrated (Step 2). Iterating with Steps 5 and 6; we can conceive a roadmap to develop the required key competencies for sustainability that leads to development of sustainability mindset among DCHE students over the 3-year duration of the program. It is especially important to review the appropriateness of each UN SDG, to ascertain each can still provide the desired context, as a result of any rationalization exercise to harmonize overall coverage as opposed to individual integration in respective modules. One should also take advantage of any opportunity that enable other UN SDG(s) to be added to achieve greater synergy with existing the goals in the individual module. It is also worth noting that the DCHE curriculum offered 2 strands of learning using the same chemical engineering principles: (1) Process Design & Operation, and (2) Product Design & Development; for which the development pathways for key competencies for sustainability may likely require different learning contexts to achieve the IChemE priority areas of process safety and digitalization.

Some of the areas of improvement are discussed below.

Values thinking competency can be introduced in the module *Introduction to Chemical Engineering* when students are first exposed to ethical dilemma as part of their exposure to roles and responsibilities as a chemical engineer. Values thinking competency can be developed alongside systems thinking competency, awareness of which can start in Year 1. An example would be in Year 1 Semester 1 when students are tasked to fabricate a portable water filter in one of the activities for *Laboratory & Process Skills 1*, for example in the use of renewable resources as filter casing, and decision regarding choice of filter media. One could also leverage on the learnings from CCC module *Thinking Critically about the UN SDGs* where students are exposed to fake news or discern different viewpoints.

Table 7. Mapping of Key Competencies for Sustainability in the DCHE Curriculum

Year and Semester	Module Name (* = CCC module)	Key Competencies for Sustainability Existing Coverage shown with '✓' Potential Coverage shown with '+'							
		Systems Thinking Competency	Futures Thinking Competency	Values Thinking Competency	Strategic Thinking Competency	Interpersonal Competency	Intrapersonal Competency	Implementation Competency	Integrated Problem-solving Competency
Year 1 Semester 1	Introduction to Chemical Engineering								
	Chemical Engineering Thermodynamics								
	Laboratory & Process Skills 1	+	✓			✓	✓		
	Thinking Critically about UN SDGs*		✓						
	Data Fluency*					✓			
Year 1 Semester 2	Heat Transfer & Equipment								
	Fluid Flow & Equipment								
	Laboratory & Process Skills 2	+				✓			
	Digital Communication for Impact*								
	Collaboration in Digital Age*					✓			
	AI and Its Impact*								
Year 2 Semester 1	Introduction to Chemical Product Design	✓				✓		✓	
	Separation Processes								
	Process Instrumentation & Control								
	Process Operation Skills 1		✓			✓	✓		
	Persuasive Communication with Data Storytelling*					✓			
Year 2 Semester 2	Chemical Product Design & Development	✓		✓		✓		✓	
	Chemical Reaction Engineering					✓			
	Chemical Engineering Design Calculations & Simulations	+							
	Process Operation Skills 2		✓			✓			
	Sustainable Innovation Project*	✓				✓		✓	✓
	Effective Writing for Workplace*								
	Problem Solving with Creative and Computational Thinking*								
Year 3 Semester 1	Plant Design, Economics and Sustainable Development			+	+	✓			
	Biopharmaceutical & Pharmaceutical Engineering								
	Biopharmaceutical & Pharmaceutical Practice					✓			
	Process Plant Safety and Engineering Ethics	✓					✓		
	Personal Branding and Career Agility*								✓
	Final Year (Capstone) Project	✓	✓	+	+	✓		✓	✓
Year 3 Semester 2	Internship Programme (22 weeks)	✓	✓			✓	✓	+	✓

These competencies are then further enhanced in Year 2 to increase students' proficiency level, especially for *Introduction to Chemical Product Design*, and *Chemical Product Design & Development*. Currently, in this area students are required to produce some prototypes of their design, and to consider the product life cycle of the product that they constructed. Since the prototype may not use the actual materials of construction intended for the proposed product (especially a "quick-and-dirty" type, or one that was 3-D printed), it would be important for students to develop values thinking and systems thinking competencies to evaluate (considering circularity or end-of-life issues) on the choice of materials used. Reflecting the inter-dependency of the key competencies for sustainability; futures thinking competency can also be developed alongside values thinking competency. An example would be getting students to think about current sustainability issues and to articulate their own vision of the desired future scenario. This can be integrated into the same learning touchpoint mentioned earlier.

These competencies can be linked back to the proper UNSDG(s). For example, students can be asked to justify how they considered responsible consumption and production in their design and development work which aligns with UN SDG #12 or to explain how their prototype/product is sustainable or deliberative changes needed to make it more sustainable. For the Year 3 *Capstone Project* a compulsory assessment can be included, that require students to explain how the outcome of their project could lead to undesirable future states, for example by demonstrating use of sustainable designs, materials and/or system etc.

Unlike interpersonal competencies which was very well covered, intrapersonal competencies will need to be further enhanced. This is perhaps the most challenging key competency to develop in a curriculum, as it aims to address issues such as mindfulness, dealing with one's emotion, introspection, etc at individual level. Intrapersonal competency is closely linked to the sustainability mindset principles advanced by the work of Isabel Rimanoczy (see for example: Rimanoczy, 2021; Rimanoczy & Llamazares, 2021). Within the curriculum, students can be tasked to write reflection journals on their experiences from sustainability-themed learning touchpoints. These can be supplemented by co-curricular activities or learning outside the classroom such as health and mental wellness programs already offered by SP.

As for strategic thinking competency, its current coverage is limited. Much like other key competencies for sustainability, strategic thinking competency is closely linked to systems thinking, values thinking and futures thinking competencies (Wiek et al, 2011). We opined that strategic thinking competency is somewhat more abstract for diploma-level students and coverage at the awareness level would suffice. One area where it can be integrated into the DCHE curriculum is in *Final Year (Capstone) Project* that requires students to consider – albeit theoretically – how to engage key stakeholders in executing their product idea, along with implementation competency.

Last but not least important, is the role of faculty, in the development of key competencies for sustainability. Faculty are the main change agent who needs to deliver the curriculum and hence must also have good understanding about these competencies so that they can craft meaningful learning activities for students and facilitate the thinking process. It is important for faculty members to have a good grasp of what to teach, how to teach, when to teach and why need to teach to diploma students. Appropriate continuing professional development programs need to be identified.

Finally, the mapping shown in Table 1 is an on-going effort by the course management team to enhance the key competencies for sustainability in its curriculum where existing learning outcomes and learning activities are being reviewed so that appropriate competencies across different year of study can be integrated and developed using a spiral curriculum model.

Designing appropriate learning assessment would follow suit. When these are implemented, a program evaluation should be done and it would serve as the basis of continuous program improvement.

CONCLUSION

This paper shared how the DCHE program from SP used an approached developed by the institution to integrate key competencies for sustainability into the curriculum to develop students' sustainability mindset. The approach detailed in this paper afforded the identification of modules in the DCHE program where the underpinning skills and attitudes for some key competencies for sustainability needed in the context of chemical engineering were already integrated; as well as pinpointing areas were others need to be enhanced. The findings also highlighted the interconnectedness between key competencies for sustainability, much like the UN SDGs. This outcome will further strengthen the development of digital and human skills initially introduced via CCC modules, to address selected UN SDGs aligned within the disciplinary context and aligned to the requirements of the accreditation body of the program. It is also suggested that the chemical engineering program uses systems thinking competency as the "backbone" around which other key competencies for sustainability – notably intrapersonal, interpersonal, values thinking, futures thinking, strategic thinking and implementation – to drive the learning process toward integrated problem-solving competency, leading to the development of students' sustainability mindset.

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Appendix 1. Matrix of CDIO Syllabus (v3.0) vs Key Competencies for Sustainability

(Adapted from Rosen et al, 2019)

MAPPING AGAINST SUSTAINABILITY COMPETENCIES		CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS	Systems Thinking	Futures Thinking	Valeus Thinking	Strategic Thinking	Interpersonal	Intrapersonal	Implementation
2.1 ANALYTIC REASONING AND PROBLEM SOLVING	2.1.1	*Problem Identification and Formulation*	✓✓✓	✓	✓				
	2.1.2	*Formulate a Strategy to Solve Problems*	✓✓✓	✓		✓			
	2.1.3	*Analyze Results*	✓✓✓						
	2.1.4	*Conclude Study and Make Recommendation*	✓✓✓						
2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY	2.2.1	*Formulate Hypothesis*	✓						
	2.2.2	*Conduct Literature Review*	?						
	2.2.3	*Conduct Experimental Inquiry*	✓						
	2.2.4	*Analyse Data and Write Report*							
2.3 SYSTEM THINKING	2.3.1	*Understand the basis and methods of system thinking*	✓✓✓		✓				
	2.3.2	*Understand Interactions in Systems, and External to Systems*	✓✓✓	✓✓✓	✓				
	2.3.3	*Apply System Thinking in Problem-Solving*	✓✓✓		✓				
	2.3.4	*Understand Trade-offs, Synergies, Judgment and Balance in Resolution*	✓✓✓	?	✓✓✓	✓✓✓			
2.4 ATTITUDES, THOUGHT AND LEARNING	2.4.1	*Demonstrate Positive Attitude and Willingness to Make Decisions in Face of Uncertainty*	✓	✓				✓	
	2.4.2	*Demonstrate Perseverance, Sense of Urgency and Will to Deliver*	✓	?		✓	✓	✓	
	2.4.3	*Demonstrate Resourcefulness and Flexibility in Adapting to Change*	✓	?				✓	
	2.4.4	*Demonstrate Creative Thinking*	✓						
	2.4.5	*Demonstrate Critical Thinking*	✓✓✓	✓	✓	✓	✓		
	2.4.6	*Demonstrate Self-Awareness, Self-Reflection, Metacognition and Knowledge Integration*		✓✓✓	✓			✓✓✓	
	2.4.7	*Demonstrate Learning Agility, Engage in Lifelong Learning and Educating*	✓					✓✓✓	
	2.4.8	*Manage Time, Technology and Resources*	✓	✓✓✓		✓✓✓			
2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES	2.5.1	*Apply Knowledge of Sound Values and Ethics, and Demonstrate Social Responsibilities*			✓✓✓		✓		
	2.5.2	*Demonstrate Professional Behaviour at Work and in Society*		?	?		✓	✓	
	2.5.3	*Develop Self-Awareness in Life Planning*		?	?		✓	✓✓✓	
	2.5.4	*Stay Current on One's Own Professional Field (e.g. Engineering, Business, etc)*	✓	✓		?		✓	
	2.5.5	*Demonstrate Respect for Equity, Justice, Diversity and Inclusiveness*					✓✓✓		
	2.5.6	*Exhibit Trust and Loyalty*					✓✓✓		
3.1 TEAMWORK AND COLLABORATION	3.1.1	*Form Effective Teams*					✓✓✓		
	3.1.2	*Manage and Participate in Teams*					✓✓✓		
	3.1.3	*Participate in Multi-perspective Collaboration*					✓✓✓		
	3.1.4	*Engage Stakeholder, Establish Diverse Connections and Networking*		✓		✓	✓✓✓		
3.2 COMMUNICATION	3.2.1	*Design Appropriate Communications Strategy*				✓			
	3.2.2	*Design Appropriate Communication Structure*							
	3.2.3	*Demonstrate Effective Written Communication*							
	3.2.4	*Demonstrate Effective Digital Communication*							
	3.2.5	*Demonstrate Effective Graphical Communication*							
	3.2.6	*Demonstrate Effective Oral Presentation*							
	3.2.7	*Demonstrate Effective Interpersonal Communication, Inquiry, Listening, Dialog and Argumentation*			✓		✓✓✓		
	3.2.8	*Demonstrate Effective Negotiation, Compromise and Conflict Resolution*			✓✓✓	?	✓✓✓		
	3.2.9	*Demonstrate Advocacy*	✓	✓		?		?	

MAPPING AGAINST SUSTAINABILITY COMPETENCIES		CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS	Systems Thinking	Futures Thinking	Valeus Thinking	Strategic Thinking	Interpersonal	Intrapersonal	Implementation
4.1 EXTERNAL, SOCIETAL AND ENVIRONMENTAL CONTEXT	4.1.1	*Identify Roles and Responsibility of Engineers or Other Professionals*			✓	✓		✓	
	4.1.2	*Address the Impact of Engineering on Society and the Environment*	✓✓✓	✓✓✓	✓	✓		✓	
	4.1.3	*Recognise How One's Profession is Regulated in Society*	✓✓✓		?			✓	
	4.1.4	*Understand Historical and Cultural Context in Engineering or Other Professions*	?		?				
	4.1.5	*Understand Contemporary Issues and Values*	✓		✓✓✓				
	4.1.6	*Describe a Vision for the Future*	✓	✓	?	?		✓	
	4.1.7	*Develop an International and Global Perspective*			✓✓✓	✓✓✓			
4.2 ENTERPRISE AND BUSINESS CONTEXT	4.2.1	*Appreciating Different Enterprise Cultures*	?		?				
	4.2.2	*Understand Different Enterprise Stakeholders, Strategy and Goals*	?		✓		✓		
	4.2.3	*Understand Technical Entrepreneurship*		?					
	4.2.4	*Understand Working in Local Organizations*					✓✓✓		
	4.2.5	*Understand Working in International Organizations*			?		✓✓✓		
	4.2.6	*Understand New Technology Development and Assessment*		✓		✓			
	4.2.7	*Understand Project Finance and Economics*		?	?	✓			
4.3 CONCEIVING, SYSTEM ENGINEERING AND MANAGEMENT	4.3.1	*Understand Societal and Planetary Goals and Constraints*	✓✓✓	✓	✓	✓			
	4.3.2	*Understand Needs and Goal-setting*	✓	✓	✓	?			
	4.3.3	*Evaluate Function, Concept and Architecture*	✓						
	4.3.4	*Develop System Engineering, Modelling and Interfaces*	✓						
	4.3.5	*Develop a Project Management Plan*			?	?			
	4.3.6	*Develop a Product Information and Knowledge Management Plan*							
4.4 DESIGNING	4.4.1	*Formulate the Design Process*	✓✓✓		✓	✓			
	4.4.2	*Plan the Design Process Phasing and Approaches*					?		
	4.4.3	*Utilize Knowledge in Design*							
	4.4.4	*Understand Disciplinary Design*					?		
	4.4.5	*Understand Multidisciplinary Design*		?			?		
	4.4.6	*Design for Sustainability, Safety, Aesthetics, Operability and Other Objectives*	✓✓✓	✓✓✓		✓			
4.5 IMPLEMENTING	4.5.1	*Design a Sustainable Implementation Process*	✓✓✓	✓		✓			✓✓✓
	4.5.2	*Plan Hardware Manufacturing Process*		?			?		✓✓✓
	4.5.3	*Plan Software Implementing Process*		?			?		✓✓✓
	4.5.4	*Plan Hardware-Software Integration*		?			?		✓✓✓
	4.5.5	*Conduct Test, Verification, Validation and Certification*				?			✓✓✓
	4.5.6	*Manage Implementation Process*	?			?			✓✓✓
4.6 OPERATING	4.6.1	*Design and Optimizing Sustainable and Safe Operations*	✓✓✓	✓	✓	✓			
	4.6.2	*Plan Training and Operations*				?			
	4.6.3	*Plan Support for Product, Process, Service, System Life Cycle*	✓			?			
	4.6.4	*Manage System Improvement and Evolution*		?		?			
	4.6.5	*Manage Disposal, Circularity and Life-End Issues*	✓✓✓			✓			
	4.6.6	*Plan for Operations Management*	✓✓✓	✓		✓			

Any cell with 3 or more (✓✓✓) will be recorded as such. Same for 3 or more (✓). Entry with mix of (✓✓✓) and (✓) will be recorded as (✓). Entry with (✓✓✓) or (✓) AND (?) will be recorded as (?). Entry with 1 (✓) and 1 or more (?) will be left BLANK.

✓✓✓ Explict / Strong ✓ Implicit / Partial

? Potential / Need for Improvement

FLIPPED LEARNING TO FOSTER STUDENTS' SELF-DIRECTED LEARNING: A STUDY OF FIRST YEAR STUDENTS' SELF-DIRECTED LEARNING COMPETENCIES

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ABSTRACT

A key goal of higher education is to cultivate self-directed, lifelong learners who can adapt to dynamic industry demands through continuous skill refinement and learning. To support this goal, Singapore Polytechnic has implemented Flipped Learning across all its programs. This learner-centered approach requires students to engage with online materials independently, fostering responsibility for preparation and understanding. By promoting essential Self-Directed Learning (SDL) skills, Flipped Learning equips students for academic success and lifelong adaptability. In 2023, the institution launched a study to evaluate the impact of Flipped Learning on students' SDL development over three years (2023 – 2026). Using the Motivated Strategies for Learning Questionnaire and student interviews, this paper presents early findings of the study involving 1188 first year students, revealing that the institution's first year students perceive flipped learning as beneficial, feel confident in their learning abilities, and adopt strategies like checking with peers and looking for resources. These findings aim to promote understanding of Flipped Learning's role in developing SDL in higher education and provide actionable insights for educators and policymakers.

KEYWORDS

Self-directed Learning, Flipped Learning, Assessment, Self-Efficacy, Metacognitive Self-regulation, Standards 8, 11

INTRODUCTION

In an era of rapid technological advancements and evolving workforce demands, the ability to be independent and adaptive learners has become a critical skill for success. Higher education institutions are increasingly tasked with preparing graduates to be self-directed lifelong learners capable of navigating complex and uncertain environments. Recognising this need, Singapore Polytechnic (SP) implemented and leveraged on flipped learning as an institution-wide pedagogy to foster SDL competencies in students (Leong et al., 2019). Flipped learning, also referred to as the flipped classroom model, reverses the traditional instructional approach by shifting content delivery outside the classroom, often through online resources such as videos (Aidoo et el., 2022). In-class time is dedicated to interactive and application-based activities (Kurbanoğlu & Akkoyunlu, 2017). In this model, students engage with instructional material independently before class (Tsai, 2021), while classroom sessions focus on activities such as problem-solving, discussions, and collaborative projects (Hwang et al., 2015). This approach allows educators to create more dynamic and student-centered learning environments, providing opportunities for timely and targeted support during in-class activities (Lo & Hew, 2021).

This paper presents preliminary findings from first year students at the beginning of their 3-year course from 2023 to 2026 and builds on Leong et al. (2024) which began exploring the impact of flipped learning on SDL competencies. The earlier study provided valuable insights into students' perceptions of their learning strategies and self-efficacy. It highlighted the potential of flipped learning to enhance SDL but the study was limited in scope and duration as compared to the current research. This study delves deeper into the effects of this pedagogical approach and adopts a mixed methods approach. A quantitative survey was employed to examine students' motivation for learning and their use of various learning strategies, complemented by qualitative data from semi-structured interviews. The preliminary findings provide insights to guide the institution in enhancing support for students and improving their learning experiences. It is important to note that the study does not examine the relationship between students' self-directed learning (SDL) competencies and their academic performance, as the focus is on understanding SDL development rather than measuring academic outcomes. This paper also conveys key takeaways from the study thus far, contributing to the understanding of SDL development in higher education.

LITERATURE REVIEW

A key benefit of flipped learning is its potential to enhance SDL skills (Kim & Lim, 2021). By requiring students to take responsibility for engaging with preparatory materials, the model encourages the development of essential skills such as self-regulation, time management, and critical reflection (Öztürk, & Çakıroğlu, 2021). A study by Alsancak and Ozdemier (2018) examined the impact of flipped learning on students' SDL readiness and findings showed that there was a significant difference for the experimental group versus the control group in terms of motivation and SDL readiness. Additionally, the classroom activities potentially promote deeper understanding through active participation and peer collaboration (Steen-Utheim & Foldnes, 2018). Despite these advantages, successful implementation depends on thoughtful planning and addressing challenges such as varying levels of student readiness, motivation and access to online resources (O'Flaherty & Phillips, 2015; Tomas et al., 2019). With careful design and execution, flipped learning can serve as a valuable tool for fostering SDL in diverse educational settings.

The topic of self-directed learning has been explicitly documented in the CDIO syllabus version 3.0 under the subcategory “Learning Agility, Lifelong Learning and Educating” (Malmqvist et al, 2022). Topics relevant to SDL in this subcategory include:

- The motivation for continued self-education
- The skills of self-directed learning
- Learning from experiences through reflective practice
- Flexibility in one’s learning approaches
- Enabling learning in and from others

Reflection of experiences play a key role in the development of self-directed learning. Bolm et al (2023) reported the importance of incorporating reflection activities and assignments into the curriculum of a Bachelor of Architecture, Urbanism and Building Sciences in the Netherlands to promote self-directed learning. Teacher behaviours are also important in promoting self-directed learning. Cabo and Klaassen (2019), for example, reported a study of teacher cues on self-directed learning in math education that there are possible relations between the teachers’ behaviour and perceived cues by students and their active engagement when blended learning is adopted. The teacher made a difference in stimulating self-regulation and influencing how independently and actively students engaged in their learning.

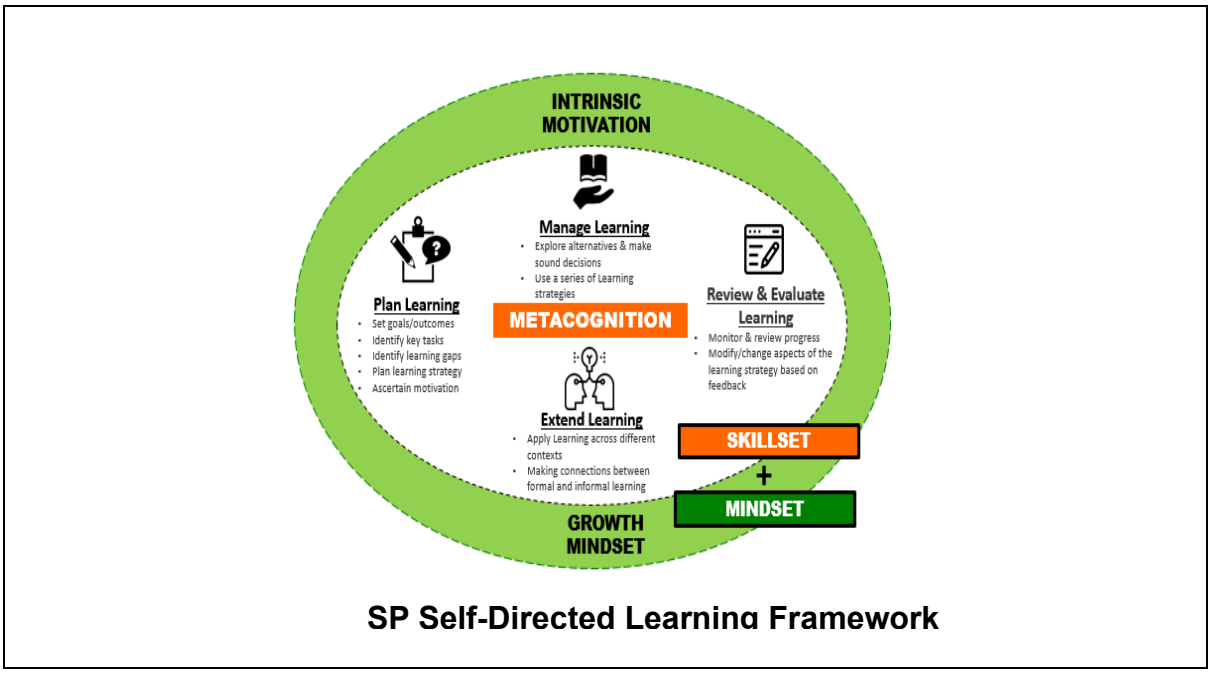


Figure 1: Singapore Polytechnic’s Self-directed Learning Framework

In SP, the curriculum has been redesigned to promote the development of self-directed learning competencies with flipped learning. An SDL framework (Figure 1), which provides the theoretical background consisting of 2 key components, has been adopted:

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.

METHODOLOGY

Quantitative Phase

The objective of the survey was to ascertain the development of students' self-directed competencies in terms of their motivation for learning and their use of different learning strategies. Pintrich's (1991) Motivated Strategies for Learning Questionnaire (MSLQ) was used for this study. It uses a 7-point Likert scale to capture nuanced differences in student motivation and learning strategies. A 7-point scale provides a wide range of options that enables participants to express varying degrees of agreement (Strongly Agree:7) or disagreement (Strongly Disagree: 1) and improves the sensitivity and reliability of the data. The MSLQ instrument was selected as it is a validated questionnaire whose components could be used singly and it has been used in a number of similar flipped learning studies that investigated SDL development.

A total of 34 questions were adopted from MSLQ. 12 questions were adopted from 2 components of the "Motivation" scale: "Self-Efficacy for Learning & Performance" and "Control of Learning Beliefs". 22 questions were adopted from 3 components of the "Learning Strategies" scale: "Help-Seeking", "Elaboration" and "Metacognitive Self-Regulation (MSR)". The survey was administered through a web-based survey application to all 4053 first-year students towards the end of the academic year. Student participation in the survey was voluntary but not anonymous to ensure the tracking of individual data throughout the duration of the study. Participants were informed of their right to withdraw from the study at any time without penalty, and care was taken to avoid any potential coercion or undue influence. To safeguard participant privacy, all data were securely stored and accessible only to authorised researchers. Identifiable information was coded and anonymized during analysis.

Qualitative Phase

The objective of the interviews was to get further insight into the quantitative results by gathering the personal experiences and reflections of students who experienced flipped learning. Students were selected from criteria such as entry scores, mid-semester test scores and prior educational backgrounds. The semi-structured interview questions were developed based on the SP SDL framework. Individual interviews were conducted online by the researchers and the recordings were transcribed verbatim for thematic coding. Participants were assured that their responses would be kept confidential, and all identifiable information was removed or coded during the transcription and analysis process to protect their privacy. Data were securely stored and accessible only to the research team. Efforts were made to minimise potential discomfort or stress during the interviews, and participants were given the opportunity to review and clarify their responses if needed.

PRELIMINARY FINDINGS

The survey received 1188 responses or about 29.3% of the 4053 first-year full-time diploma students in SP participated in the survey. There was representation from all courses within the institution. Figure 2 shows the findings for all MSLQ components.

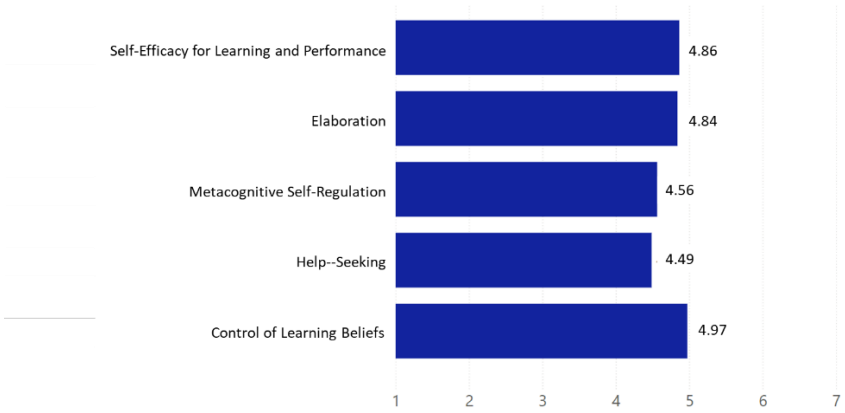


Figure 2: Results for all MSLQ Components

The figure shows that respondents rated themselves highest when it comes to being in Control of Learning Beliefs, followed by Self-Efficacy for Learning and Performance, and lowest for Help-Seeking. Figures 3, 4 and 5 show the detailed findings for these components.

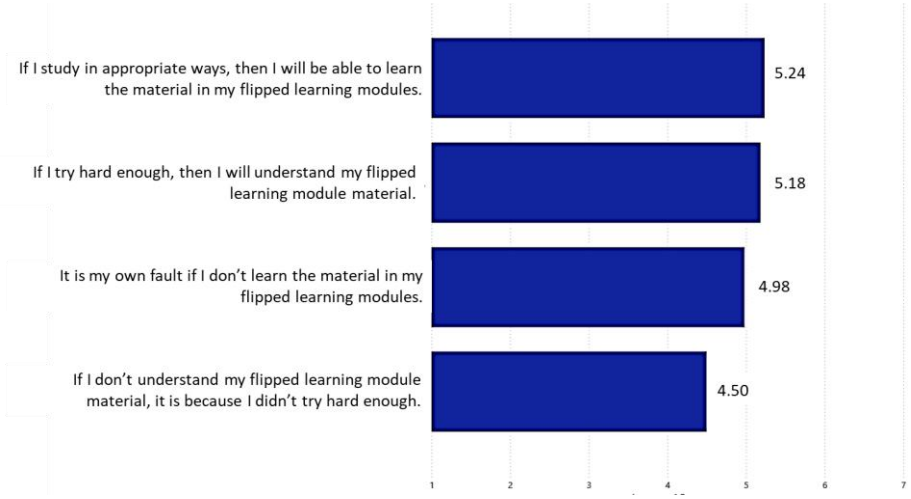


Figure 3: Results for the Control of Learning Beliefs scale

Figure 3 shows the findings for the Control of Learning Beliefs (CLB) scale. The mean scores of the CLB scale ranged from 4.50 to 5.24 with an overall mean of 4.97 (SD = 1.5). The Cronbach alpha was 0.879 which showed good internal consistency in the student responses. The figure shows that that most of the student respondents believe that studying in appropriate ways will enable them to learn the material (mean = 5.24) but if they did not understand the material, it was not their fault (mean = 4.98) and it was not because they did not try hard enough (mean = 4.50).

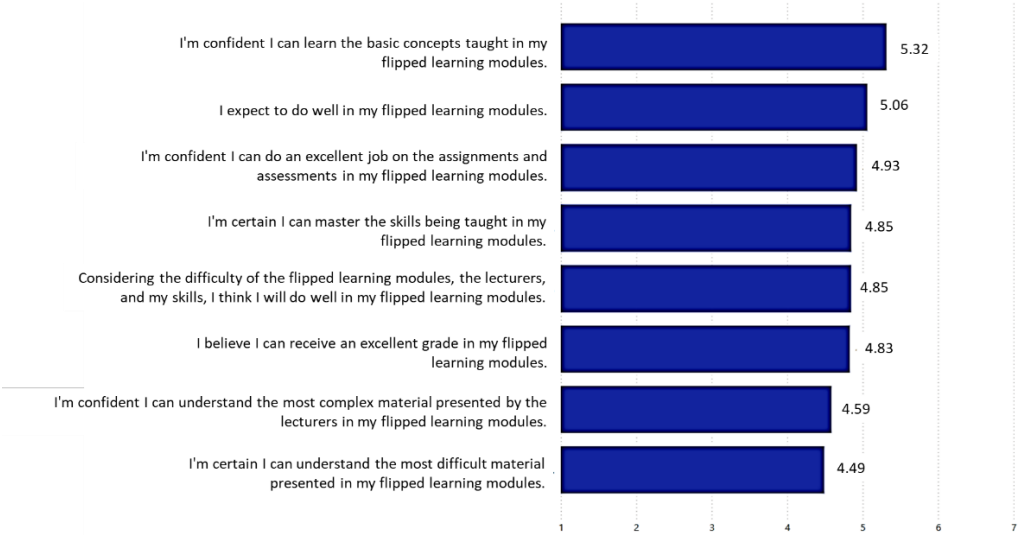


Figure 4: Results for the Self-Efficacy for Learning and Performance Scale

Figure 4 shows the findings for the Self-Efficacy for Learning and Performance (SE) scale. The mean scores of the SE ranged from 4.49 to 5.32 with an overall mean of 4.86 (SD = 1.4). The Cronbach alpha was 0.964 which showed excellent internal consistency in the student responses. The figure shows that that most student respondents perceived themselves to be confident of learning the basic concepts taught in their flipped learning modules (mean = 5.32) and expect to do well (mean= 5.06) for their flipped learning modules. However, respondents perceived themselves as least confident when it comes to learning the most complex concepts and most difficult material in their flipped learning modules (means= 4.59 and 4.49).

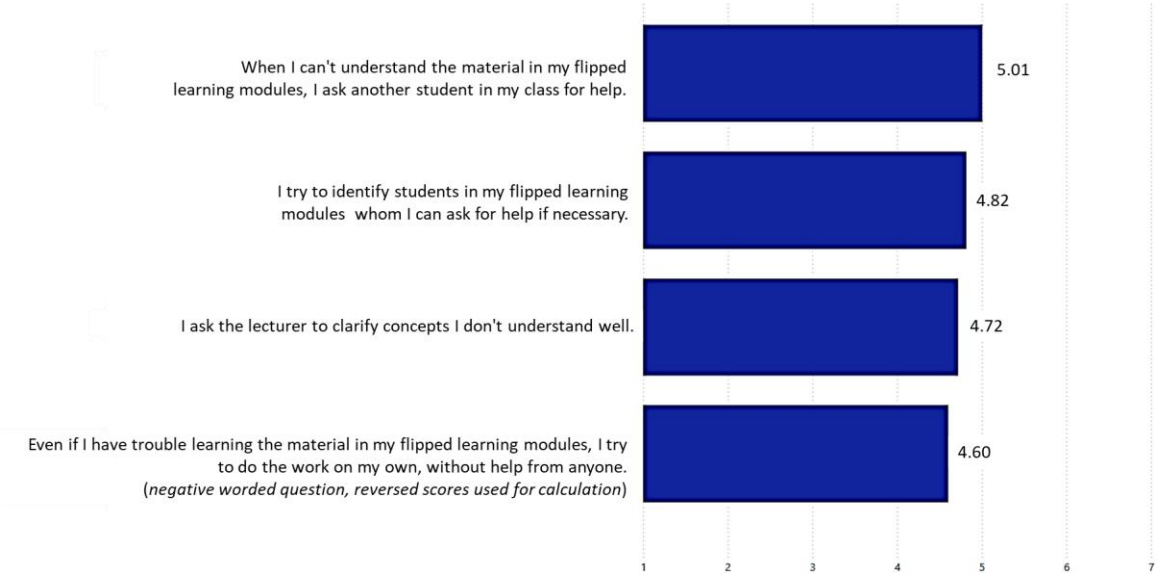


Figure 5: Results for the Help-Seeking Scale

Figure 5 shows the findings for the Help-Seeking scale. The mean scores of the MSR ranged from 4.60 to 5.01 with an overall mean of 4.97 (SD = 1.7). The Cronbach alpha was 0.755 which showed acceptable internal consistency in the student responses. The figure shows that for help-seeking practices, most student respondents perceived that they would ask another student in class for help (mean= 5.01 and 4.82), followed by asking their lecturers (mean= 4.72).

34 students were interviewed during the qualitative phase of this study. Students were nominated by their lecturers based on their academic performance, selecting both high-performing and underperforming students to capture a balanced range of perspectives and experiences. Thematic coding of the interview transcripts was carried out to triangulate with the MSLQ findings and gain further insight with anecdotal evidence.

The survey results showed that most student respondents believed that using effective study methods would help them learn the material. This was supported by qualitative findings, where many interviewed students reported improving their learning strategies in the flipped classroom. The two most common practices mentioned were seeking additional resources (n=25) and discovering new study methods (n=11).

Student 1 said this when asked how he engaged with resources to learn the materials:

"I only started using AI after I came to this school. I realised it helps a lot. And for research, I've never actually went to watch, like online videos last time, but now I do when I don't understand anything online. I'll just search Google and then I watch a YouTube video to see the visuals then I will understand it better."

Student 2 described having to learn new ways to study before the in-class sessions:

"I think that by preparing myself before every class, I know what is to be expected. And this helped me to take better notes…I think this also helped me to have a deeper understanding of the topic because I don't spend hours trying to memorise and understand the theories that are being taught in class but rather think of how I'm going to apply these skills in my future projects."

The online learning content being too difficult (n=8) is a possible reason uncovered from the qualitative analysis as to why many student respondents perceived more difficulty in understanding complex and difficult material and perceived that if they did not understand the material, it was not their fault. As Student 3 shared:

"So I had a lot of clarification that I needed to do with my friends and my teachers after that, because the content in the smart book wasn't very easy to understand, and there wasn't like any other video content that we could listen to actually clarify further"

The qualitative findings also corroborated the more common help-seeking practices shown by the survey findings as more student respondents reported they would check with their peers (n=13) and with their lecturers (n=11).

Student 4 had this to say about checking with peers:

"I always consult with my classmates and my friends. And always see like how, like how they have done a certain project. And I want to see the difference. What am I missing? What am I doing that is not the same? So I want to see the difference."

Student 5 explained the rationale and the benefits for checking with the lecturer:

"I also feel that checking in with my lecturer is a way to validate because during every normally there's an intermission during class. And how I will check my learning is by giving my lecturer a short recap about what I've learned. And if the lecturer feels that I missed out

some pointers, he will also highlight whether my understanding is correct or wrong. And I think this has really helped me over the past year."

DISCUSSION AND CONCLUSION

The findings from this study reflect first year students' initial experiences of and adaptations to flipped learning but further analysis over time will offer a deeper understanding of how these trends evolve. The survey revealed that first year students felt most confident in their control over learning beliefs and self-efficacy for learning and performance, but less confident when it came to help-seeking. The qualitative findings supported these trends, highlighting that students have adopted various strategies such as seeking additional resources (e.g., AI tools and online videos) and learning new study methods. However, the challenges reported with complex content and the continued reliance on peer and lecturer support suggest that their learning strategies are still developing. While challenges with difficult and complex content persist, help-seeking practices are important for overcoming such difficulties

As this study is part of a long-term study, future phases of data collection will provide a clearer picture of how students' motivation, self-regulation, and learning strategies change over time, offering deeper and long-term insights into the potential of flipped learning for students' SDL development.

Despite the promising results, the study has limitations. Firstly, self-reported survey responses may introduce biases, as students' perceptions of their learning competencies might not fully align with their actual behaviors. Another possible limitation could be the delivery of flipped learning by lecturers. Variations in lecturers' competencies in designing and facilitating flipped classroom activities may have influenced the consistency and effectiveness of the student learning experience. Finally, the initial phase of the study primarily captures short-term effects of flipped learning, with longer-term impacts yet to be examined in subsequent phases of the research. The study also does not include a comparison of SDL development with academic performance, highlighting an area for further investigation.

The research study will continue with the same cohort of students to further explore the effects of the institution-wide adoption of flipped learning pedagogy. Annual surveys will be administered in their remaining two academic years to track SDL development, complemented by more interviews to understand students' actual practices.

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SIX MONTHS OF ENGINEERING WITH CDIO APPROACH

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ABSTRACT

This paper reflects on a series of engineering events and competitions organized over six months at our university, aligned with the CDIO (Conceive, Design, Implement, Operate) approach. These activities aimed to engage students in engineering challenges that bridge theoretical knowledge with practical application. The events included workshops and design competitions, fostering problem-solving, teamwork, and critical thinking while igniting student interest in engineering. Innovative methods were employed to attract students, ensuring the activities were engaging and relevant. The events guided participants through all CDIO stages, creating a dynamic learning environment. Students were encouraged to take ownership of their projects, gaining exposure to real-world engineering applications. To evaluate the effectiveness of these initiatives, a participant survey was conducted. Feedback was collected on engagement levels, skill development, and the impact of the CDIO framework on their understanding of engineering principles. The survey revealed that students found the events highly engaging and beneficial. The hands-on approach and focus on real-world problems provided deeper insights into engineering concepts compared to traditional classroom learning. Collaborative elements fostered teamwork and communication, essential for engineering success. Participants noted that the CDIO framework helped them develop a structured approach to problem-solving, valuable in both academic and practical settings. The findings underscore the potential of the CDIO framework to enhance engineering education by offering comprehensive, hands-on experiences. These activities resonate with students' interests and career aspirations, improving learning outcomes and fostering a stronger connection to the engineering profession. The success of these events demonstrates the value of the CDIO approach in creating meaningful, engaging, and effective engineering education experiences, paving the way for future initiatives that align with student needs and industry demands.

KEYWORDS

Introduction to Engineering, CDIO skills development, professional skills, CDIO Standards: 1, 3, 4, 6

INTRODUCTION TO SIX MONTHS OF ENGINEERING

Engineering education must evolve to meet the growing demands of modern industries. The integration of theoretical knowledge with practical applications is critical for preparing students for real-world challenges. The CDIO framework provides a structured and innovative approach to achieving this goal, emphasizing problem-solving, teamwork, and critical thinking. This paper discusses a six-month initiative at Oguz han Engineering and Technology University of Turkmenistan (ETUT), where a series of engineering events and competitions were organized under the CDIO framework. These activities aimed to bridge the gap between academic learning and practical application, fostering student engagement and professional development.

The program was designed to address key aspects of engineering education, including hands-on learning, professional skills development, and exposure to real-world challenges. Through workshops and design competitions, students were encouraged to explore engineering concepts creatively and collaboratively. This initiative highlights the importance of experiential learning and aligns with global trends in engineering education, where practical skills are increasingly valued alongside theoretical knowledge.

Objective of the Research

The primary objective of this research was to evaluate the effectiveness of the CDIO framework in enhancing engineering education at ETUT. This initiative aimed to address the limitations of traditional engineering curricula, which often emphasize theoretical knowledge while offering limited opportunities for practical application. By organizing a series of workshops and competitions over six months, the study sought to bridge this gap, providing students with hands-on experiences that align with real-world engineering challenges.

One key objective was to assess how well the CDIO framework engages students in active learning. Engineering education is most effective when students are not merely passive recipients of information but are actively involved in the learning process. This research aimed to determine whether the CDIO approach could foster such engagement by encouraging students to take ownership of their projects and actively participate in problem-solving activities. Another critical objective was to evaluate the impact of the CDIO framework on skill development. Modern engineering demands a combination of technical expertise and professional skills, such as teamwork, communication, and critical thinking. The initiative was designed to cultivate these competencies by requiring students to work collaboratively, articulate their ideas effectively, and think critically about complex engineering problems. The research sought to measure improvements in these areas and understand how the CDIO framework contributes to their development.

Additionally, the research aimed to explore the relevance of the CDIO framework in preparing students for industry demands. Engineering graduates often face challenges when transitioning from academic environments to professional settings due to a lack of practical experience. By simulating real-world scenarios, the CDIO approach provides students with an opportunity to apply theoretical knowledge in practical contexts. This study sought to determine whether such experiences enhance students' readiness for professional engineering roles and their ability to adapt to industry expectations.

The research also aimed to gather insights into student perceptions of the CDIO framework. Understanding how students view this approach is crucial for evaluating its effectiveness and identifying areas for improvement. By collecting feedback through surveys and interviews, the study sought to uncover students' perspectives on the learning process, the challenges they faced, and the benefits they derived from participating in CDIO-based activities.

MATERIALS AND METHODS

The six-month initiative at ETUT was meticulously planned and executed to maximize student engagement and learning outcomes. The program consisted of multiple interconnected activities designed to guide students through the CDIO stages, providing them with a comprehensive understanding of engineering practices. The methodology for this initiative is detailed below.

The first step involved designing events that would effectively cover all stages of the CDIO framework. A multidisciplinary team of faculty members and engineering professionals collaborated to create a series of workshops and competitions that were both challenging and engaging. The goal was to design activities that not only stimulated intellectual curiosity but also encouraged students to apply theoretical knowledge in practical settings. Emphasis was placed on real-world problems to ensure the relevance of the activities to future engineering careers.

To attract a diverse group of participants, innovative outreach strategies were employed. Announcements were made through various channels, including social media, university bulletin boards, and classroom visits. The promotional efforts highlighted the unique learning opportunities provided by the initiative, such as hands-on experience, teamwork, and the chance to tackle real-world engineering challenges. These efforts were successful in drawing a wide range of students, from freshmen to seniors, and from various engineering disciplines.

CDIO stages

In the design competitions, students were tasked with addressing specific engineering problems that required innovative solutions. The competitions were structured to guide participants through the CDIO stages. In the "Conceive" phase, students were required to identify a problem and propose a feasible solution. This phase emphasized critical thinking and creativity, as students brainstormed ideas and assessed their viability.

The "Design" phase involved detailed planning and the creation of technical drawings or blueprints. Students worked in teams to develop comprehensive project plans, incorporating feedback from mentors and peers. Collaboration was a key aspect of this phase, as it mirrored real-world engineering practices where teamwork is essential for success.

In the "Implement" phase, students brought their designs to life by constructing prototypes or models. Resourcefulness was often required, as students had to work within the constraints of available materials and tools. This phase provided hands-on experience and allowed students to see their ideas take tangible form.

Finally, in the "Operate" phase, students tested their prototypes in simulated or real-world conditions. This phase emphasized iterative improvement, as students analyzed the performance of their solutions and made necessary adjustments. The ability to refine and optimize their designs was a critical learning outcome of this phase.

Throughout the initiative, mentors played a crucial role in guiding students and providing constructive feedback. Faculty members, industry professionals, and senior students acted as mentors, sharing their expertise and offering insights into best practices. Their involvement ensured that the activities were both educational and aligned with industry standards.

To evaluate the effectiveness of the initiative, a comprehensive survey was conducted among participants. The survey included both quantitative and qualitative questions, covering aspects

such as engagement levels, skill development, and the perceived impact of the CDIO framework on their understanding of engineering principles. The feedback collected through this survey was instrumental in assessing the success of the initiative and identifying areas for improvement.

In addition to the survey, observational data was collected during the workshops and competitions. Faculty members monitored student participation and collaboration, noting instances of innovation, teamwork, and problem-solving. This data provided valuable insights into the effectiveness of the CDIO framework in fostering a dynamic and engaging learning environment.

Comparison of effect of Six months challenge

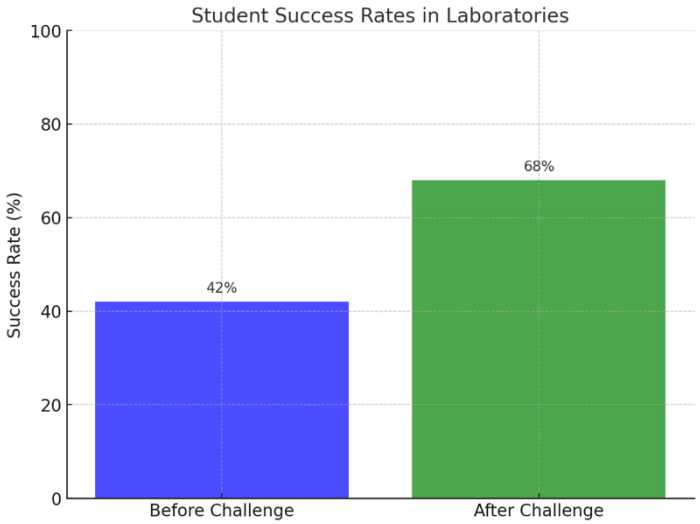


Figure 1. Student performance analysis dashboard

The Figure 1 illustrates the impact of the six-month engineering challenge on student success rates at ETUT. The data compares student performance in laboratory-based assessments before and after the challenge.

Prior to the challenge, the success rate was 42%, representing 1890 out of 4500 students achieving satisfactory results. This baseline reflects the traditional approach to engineering education, which emphasized theoretical instruction with limited practical engagement.





Figure 2. Percentage overview of results of six months challenge

After the challenge, the success rate significantly increased to 68%, equating to 3060 students demonstrating improved performance. This improvement highlights the effectiveness of the challenge in enhancing student learning outcomes through hands-on activities, competitions, and interdisciplinary projects.

The Figure 2 visually represents this progress, with two bars indicating the percentage of successful students before and after the challenge. The first bar, labeled "Before Challenge," is shorter, signifying the lower success rate, while the second bar, labeled "After Challenge," is taller, reflecting the substantial improvement.

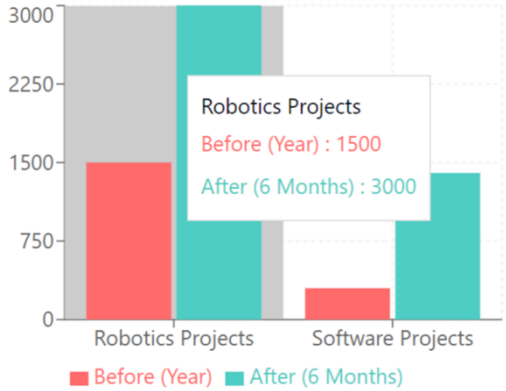
This comparison underscores the value of experiential learning and the CDIO framework in fostering academic and practical excellence in engineering education. The diagram serves as a compelling visual summary of the initiative's success in bridging the gap between theoretical knowledge and real-world application.

Impact of the Challenge on Project Output: Robotics and Software Development

The six-month engineering challenge not only improved student success rates but also significantly influenced the quantity and scope of student projects, particularly in the fields of robotics and software development. The diagram illustrates a dramatic increase in the number of projects completed in these domains, highlighting the transformative impact of the challenge on students' productivity and engagement with engineering disciplines.

Robotics Projects

Before the challenge, the annual output of robotics projects was approximately 1500. This number reflects the baseline productivity of students under traditional educational methods, where projects were often limited by a lack of motivation, resources, or opportunities for hands-



on experimentation. Robotics, being a complex and interdisciplinary field, requires a blend of theoretical knowledge and practical skills. The relatively modest output prior to the challenge indicated that students were not fully engaged or adequately supported in pursuing such projects.

Figure 3. Comparison of quantity of robotic projects (before – after)

In Figure 3 after the implementation of the challenge, the number of robotics projects surged to approximately 3000 within just six months. This doubling of output in half the usual time demonstrates the effectiveness of the challenge in fostering student interest and capability in robotics. The activities organized during the challenge, including workshops, competitions,

and mentorship programs, provided students with the tools, guidance, and motivation to explore robotics in greater depth. The CDIO framework played a crucial role in this success by encouraging students to conceive innovative ideas, design functional prototypes, implement their designs, and test their solutions in real-world scenarios.

The diagram visually represents this growth, with two bars labeled "Before Challenge" and "After Challenge" for robotics projects. The first bar, representing the annual output of 1500 projects, is significantly shorter than the second bar, which illustrates the remarkable achievement of 3000 projects in just six months. This stark contrast underscores the profound impact of the challenge on student productivity and engagement in robotics.

Software Development Projects

The field of software development also experienced a substantial increase in project output as a result of the challenge. Prior to the challenge, the annual number of software development projects was approximately 300.

This relatively low figure highlighted a need for greater emphasis on programming and software engineering in the curriculum. Many students lacked the confidence or resources to undertake software projects, resulting in limited output.

Following the challenge, the number of software projects skyrocketed to 1400 within six months. This nearly fivefold increase in output over a significantly shorter timeframe demonstrates the challenge's success in inspiring students to explore software development. The inclusion of specialized workshops on coding, algorithm design, and software engineering principles equipped students with the necessary skills and knowledge to tackle complex programming tasks. Collaborative activities further enhanced their ability to work in teams, solve problems creatively, and produce high-quality software solutions.

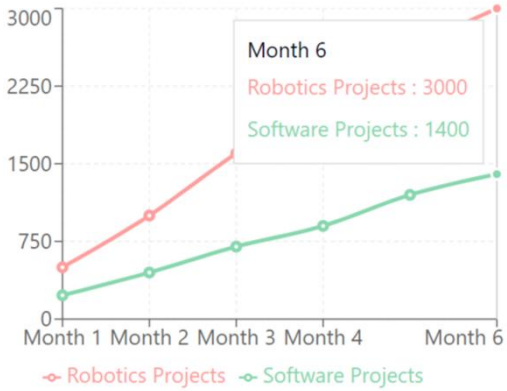


Figure 4. Monthly Progress During Challenge

The diagram visually compares these figures with two bars labeled "Before Challenge" and "After Challenge" for software projects. The first bar, representing the annual output of 300 projects, is dwarfed by the second bar, which illustrates the dramatic increase to 1400 projects in just six months. This visual contrast highlights the effectiveness of the challenge in promoting software development as a key area of focus for engineering students.

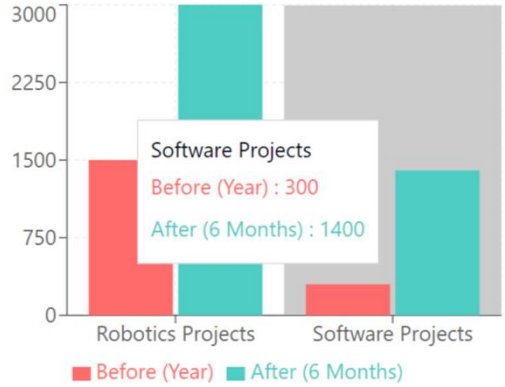


Figure 4. Comparison of quantity of software projects (before – after)

Analysis of Results

The significant increases in project output for both robotics and software development can be attributed to several factors introduced during the challenge. First, the hands-on, experiential learning approach encouraged students to actively engage with their studies and pursue innovative ideas. By providing a structured framework for project development, the challenge helped students navigate the complexities of robotics and software engineering, transforming theoretical concepts into practical applications.

Second, the collaborative nature of the challenge fostered a sense of community and shared purpose among students. Working in teams allowed participants to pool their skills and knowledge, overcome obstacles more effectively, and achieve greater success in their projects. The mentorship provided by faculty members and industry professionals further enhanced this collaborative environment, offering students valuable guidance and support throughout the project lifecycle.

Third, the competitive aspect of the challenge motivated students to push their limits and strive for excellence. The recognition and rewards associated with successful projects served as powerful incentives, driving students to invest their time and effort into creating innovative solutions. This competitive spirit, combined with the supportive learning environment, created the perfect conditions for students to excel in robotics and software development.

Innovative Festivals: Food Tech and Craft Tech

As part of the six-month initiative, two unique festivals, "Food Tech" and "Craft Tech" were organized to expand the scope of the CDIO framework and offer students creative avenues to apply their engineering knowledge. These festivals aimed to explore the interdisciplinary applications of engineering and to engage students in innovative problem-solving activities outside traditional engineering domains.

The "Food Tech" festival challenged students to integrate engineering principles and technological tools into food preparation. Participants were required to approach food as an engineering problem, considering aspects such as process optimization, precision, and innovation. For instance, students used engineering techniques to design efficient cooking

processes, measure ingredients with high accuracy, and explore innovative ways to enhance food quality. This festival demonstrated the versatility of engineering by applying its principles to a non-traditional field, encouraging students to think creatively and explore new applications of their skills.

The "Craft Tech" festival focused on blending traditional handmade art with modern technology. Students were tasked with creating functional or decorative items that combined craftsmanship with engineering techniques. Projects included integrating sensors into handcrafted items, using 3D printing to enhance artistic designs, and developing interactive art pieces. This festival highlighted the importance of creativity and interdisciplinary thinking, showing students that engineering solutions can also be aesthetically appealing and culturally significant.

CONCLUSION

The six-month initiative at ETUT, centered around the CDIO framework, has yielded significant insights into the enhancement of engineering education. This approach has effectively bridged the gap between theoretical knowledge and practical application, thereby fostering a more engaging and relevant learning environment for students. The findings from this initiative underscore the importance of experiential learning in preparing students for the challenges they will face in their professional careers. The feedback collected from participants further reinforces the positive impact of this initiative. Students reported that their involvement in CDIO-based activities not only improved their technical skills but also enhanced essential professional skills such as teamwork, communication, and critical thinking.

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DEVELOPING QUALITY MANAGEMENT COMPETENCIES IN SOFTWARE ENGINEERING: A CDIO APPROACH

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ABSTRACT

This paper explores the development of quality management within theFIRMA, a project-based learning environment at Turku University of Applied Sciences (TUAS), Finland. TheFIRMA operates like a software company, providing students with real-world experience in project management and software development. Despite its success in software development projects, theFIRMA faced challenges in quality management, particularly in maintaining long-term commitment and ownership among students. To address these challenges, several initiatives were implemented. The management team was restructured to include a Head of Operations (HOO) responsible for overseeing quality management. Quality metrics were developed to measure and improve project outcomes. New practices in project management and software development were introduced, requiring students to follow either the waterfall method or Scrum, use GANTT charts, and track tasks with Product Backlogs. Additionally, course content was updated to include information-sharing sessions, and lectures on time management and scope management. The paper discusses the impact of these changes on student learning and project outcomes, emphasizing the importance of adequate training, mentoring, and support. Future work includes finalizing the quality manual, testing quality metrics, and encouraging collaborative coding practices. Future research will include the impact on the new quality management measures to students' learning outcomes.

KEYWORDS

Quality management, quality development, Project-based learning, ICT, Standards 3, 7, 8.

INTRODUCTION TO THEFIRMA AND ITS QUALITY CHALLENGES

TheFIRMA is a project-based learning environment within the Software Engineering and Project Management (SEPM) competence track at the Turku University of Applied Sciences (TUAS) Faculty of ICT and Industrial Engineering, Finland. Established in 2015, theFIRMA operates similarly to a software company, offering a multitude of services ranging from website and web/mobile application development to marketing surveys and short-term IT support. As a student-led project office, all managerial positions are held by students, including a paid student CEO, a student Vice CEO, a student Head of Operations (HOO), and a student Marketing Manager. Together with two lecturers overseeing operations, this group forms the managerial team of theFIRMA. Each project also has a project manager or a Scrum master and various other roles depending on the project's nature, such as developers, designers, videographers, composers, social media content creators, etc.

Annually, approximately 200 undergraduate ICT engineering and business administration students participate in theFIRMA projects in various roles. In the autumn semester, second- and fourth-year students participate in project work as part of their ICT project courses, while in the spring semester, the participants are mainly third- and fourth-year students. In summer, students work in theFIRMA as interns. The simplified organization structure of theFIRMA is described in Figure 1.

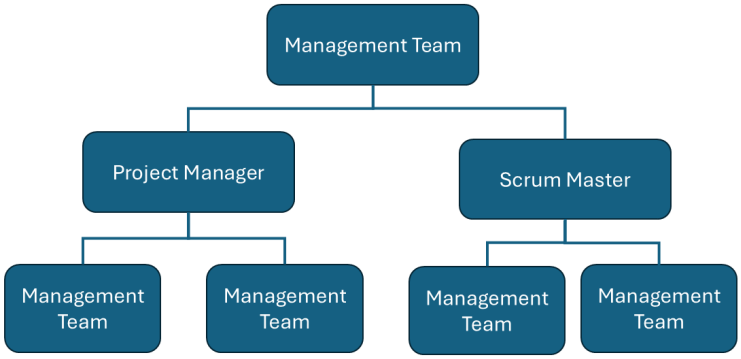


Figure 1: Simplified organization structure of theFIRMA

Course Structure and Duration

TheFIRMA is integrated into three main courses within the SEPM competence track: Introduction to ICT Projects, ICT Projects, and Advanced ICT Projects. The first two courses each take one semester, with students working 81 and 108 hours respectively. The Advanced ICT Projects course spans the entire academic year, requiring 135 hours of work. Additionally, students can earn credits for optional studies by working in theFIRMA with 27 hours equating to 1 ECTS.

During summer internships, students work 270 hours. Students can also complete their thesis in theFIRMA, either by being commissioned for specific tasks or by working on projects and writing a learning diary. These projects provide hands-on experience in project management and software engineering, aligning with the CDIO (Conceive, Design, Implement, Operate) framework to enhance learning and professional growth.

Project Categories

TheFIRMA projects can be roughly divided into three categories. The first category consists of projects for external customers, primarily small and mid-sized local companies, focusing on website design and development and web/mobile application development. TheFIRMA has also undertaken EU-funded projects aimed at developing the digital skills of small and medium-sized companies or private citizens.

The second category includes TUAS internal projects and collaborations with other universities of applied sciences in different countries (see, Säisä, et al., 2020). Internal projects are not paid and often have lower scheduling priority. The third category is the Citizen's Help Desk (KITT), which provides free IT support to local citizens, primarily elderly individuals, with issues related to their mobile devices and computers.

Growth and Quality Challenges

The aim of theFIRMA's quality assurance process is to ensure good project outcomes for customers while supporting students' professional growth. Students set learning goals at the project's start, track their working hours, and evaluate goal achievement at the end (Määttä, Roslöf & Säisä, 2018). Over the years, theFIRMA has made many changes to the project process, usually reactive and educator led. To improve quality, we added instructions to virtual learning platform, defined our project processes, and required four documents: Project Plan, Kick-off, Final Report and Project Closing. Despite these measures, we lacked a comprehensive understanding of the root causes of our challenges, such as late project deliveries and scope issues.

The rapid growth in student numbers and closer integration with SEPM track courses have presented challenges related to project quality. Since most students leave after completing their courses, project teams change almost entirely three times a year: at the beginning of autumn and spring semesters and at the start of the summer.

SEPM track adheres especially to CDIO standards 3 (Integrated Curriculum), 7 (Integrated Learning Experiences), and 8 (Active Learning) in project courses. Students learn project-related practices in lectures and then apply this theoretical learning in theFIRMA projects (Säisä, Määttä & Roslöf, 2017). This approach works very well in software development projects but poses challenges long-term quality management. The short-term nature of project courses disbands project groups, breaking the development process. Educators must pay extra attention to teaching and mentoring subsequent project teams to maintain long-term perspectives. The short-term approach hinders students from creating ownership and long-term commitment to quality, making it difficult to standardize improvements in theFIRMA processes (Tiura & Säisä, 2018).

This paper discusses how we have developed quality management in theFIRMA to better include the CDIO framework. It answers the following questions: 1) How we have developed theFIRMA quality management, so that it better implements the CDIO framework? 2) What have our experiences been with this development process? 3) What impact have these quality management improvements had on student learning outcomes and project success?

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

In an environment such as theFIRMA, the concept of quality must be considered from multiple, interrelated perspectives. Firstly, from an educational standpoint, quality is reflected in how

well the learning objectives are achieved, how students engage in authentic, practice-based learning, and how effectively the learning environment supports their professional development (Biggs & Tang, 2011). Secondly, the quality of the projects themselves must be evaluated in terms of outcomes, stakeholder satisfaction, and the value delivered to real clients. Thirdly, project management quality plays a crucial role in bridging educational goals and project success. Effective project planning, communication, risk management, and team coordination are essential for ensuring both a positive learning experience and a successful project outcome (PMI, 2017). In this type of learning-by-doing environment, quality is not a singular metric but a multi-dimensional construct that encompasses pedagogical value, technical deliverables, and managerial processes.

In project management, quality is defined as the degree to which a set of inherent characteristics fulfills requirements. Quality management ensures that the project deliverables meet both stated and implied needs, through processes such as quality planning, quality assurance, and quality control (PMI, 2017).

Educational quality in the context of a CDIO-based software engineering program is reflected in the integration of project-based learning across all study years, supporting the development of both technical competencies and professional skills. This approach ensures students gain practical experience in teamwork, design, implementation, and reflective evaluation, aligning learning outcomes with industry expectations (Levy, 2009).

The implementation of the CDIO framework in the Hacking Exposed course at Duy Tan University illustrates how integrated, project-based learning can significantly enhance educational quality. By aligning learning activities with CDIO Standards 5 and 7, students developed both technical and professional competencies through structured design-implement experiences and interdisciplinary collaboration. This pedagogical approach not only improved students' problem-solving, self-learning, and teamwork skills, but also provided practical exposure to real-world cybersecurity challenges, thereby bridging the gap between theory and industry expectations (Vo et al., 2017).

The integration of the CDIO framework into the Diploma in Chemical Engineering at Singapore Polytechnic demonstrates how structured self-evaluation can be effectively aligned with institutional quality systems and external accreditation requirements. By embedding CDIO Standards within their Academic Quality Management System (AQMS) and professional development processes, the program has systematically enhanced curriculum design, teaching quality, and student learning outcomes. This alignment enabled continuous improvement while also satisfying the rigorous expectations of external bodies such as IChemE, affirming CDIO's value in supporting high-quality engineering education (Cheah et al., 2013).

IDENTIFYING CHALLENGES IN THEFIRMA PROJECTS

To better understand the quality challenges, we investigated students' perspectives on project management. We commissioned Jani Pöllänen to research this in his thesis project. Through 17 semi-structured interviews, Pöllänen identified three major factors affecting project quality:

- *Lack of Documentation:* Inadequate documentation caused delays as new project teams struggled to understand previous work, especially when the entire team changed at the start of a new semester.

- *Time Management:* Students lacked time management skills and projects did not use tools to track schedules, making hard to monitor time against plans.
- *Communication:* Students had insufficient technological skills to use message boards effectively, missing notifications and important messages (Pöllänen, 2024).

In addition to Pöllänen's study, theFIRMA management team conducted informal discussions and reviewed projects by going through project documentation of selected projects to identify major issues that led to scheduling and scope challenges. The informal discussions were held with students working in theFIRMA in various roles to gather qualitative insights. Although these efforts were not systematic or scientifically rigorous, they revealed patterns and major issues.

To gain deeper insights into project practices, we also examined study diaries (e.g., Hermans, 2025; Jalava, n.d.). These diaries, though not focused on quality, provided valuable information about everyday practices that we do not have time to oversee. They helped us understand how projects were executed on a day-to-day basis, highlighting areas where improvements were needed.

Investigations revealed that many projects were not properly using project management tools like Product Backlogs or were using inadequate tools like Excel. This made it difficult for students to stay within scope and meet schedules. Students also did not consistently follow any project management methods, leading to impractical and inefficient ways of working and unclear responsibilities.

In application development projects, infrequent discussions on coding practices and lack of code sharing and mob coding led to merge conflicts, overlapping code, and poor variable naming. This resulted in low code quality, poor reusability, and missed bugs and functional errors, increasing technical debt and knowledge silos. In some cases, lack of collaboration necessitated extensive code rewrites.

ENHANCING QUALITY MANAGEMENT THROUGH STRATEGIC CHANGES

In the next phase, we aimed to develop theFIRMA's quality management processes within the context of the CDIO framework (standard 1, context). Our focus was on the three perspectives highlighted in the literature review: educational, project management, and project outcomes. Our investigations highlighted several areas needing improvement: restructuring the management team, developing quality metrics and a manual, enhancing project management practices, revamping the quality assurance team, and updating the project course content. The following subsections detail the specific changes and improvements we have implemented to address these challenges.

Restructuring the Management Team

From the perspective or project outcomes, one of the major issues with quality management was the lack of ownership, long-term perspective, and commitment to quality. Previously, the student CEO and student Vice CEO, along with two lecturers, oversaw operations. Both the CEO and Vice CEO already had a heavy workload and demanding schedule, so the main responsibility for quality development fell to the responsible teachers. However, this situation did not align with theFIRMA principles, where the aim is for students to take responsibility for operational activities, and teachers to have mainly a mentoring role (Tiura & Säisä, 2018).

To address this, we created the role of Head of Operations (HOO). The HOO is part of the management team and is responsible for overseeing working hours, monitoring projects, and managing and developing quality together with the quality assurance team. This role fosters ownership, commitment, and long-term perspective, while giving students responsibility and enhancing active learning, which conforms to standard 8 of the CDIO framework.

Creating Quality Metrics and Quality Manual

Another measure taken toward the improvement of the project outcomes was to find effective ways to improve the quality by providing clearer metrics and instructions. We discovered that although students take an active role in developing quality, close cooperation with responsible teachers is required. Often, the initiative for changes comes from the students rather than the teachers. One initiative that came through Pöllänen's study was to create a quality manual for theFIRMA. The management team also decided to find ways to measure quality to assess if changes have improved processes and project outcomes. The teachers decided to set these as thesis projects in early summer 2024, with an initial deadline of late December 2024.

The thesis project on metrics was exemplary, with students in various roles collaborating to create a set of metrics to measure projects effectively. Metrics include standard software company measures and pedagogical goals, such as how well students use certain tools, how frequently they meet with customers, and how consistently project management methodologies are used. Developing the quality manual as a thesis project proved challenging due to its complexity. We decided it would be more effective as a group project involving the quality assurance team and the HOO.

For thesis projects, integrating the entire CDIO cycle is difficult due to time constraints. By involving other students in discussions and contributions, we create opportunities for them to experience the full CDIO model. Teachers act as supervisors, providing guidance and oversight, while students actively participate in these projects.

Enhancing Project Management and Software Engineering Practices

From the project management perspective, we aim to follow CDIO standard 3, Integrated Curriculum. We teach project management methods like waterfall and Scrum, along with scheduling, risk, and quality management. However, students often do not use the tools and methods they have been taught in their projects.

To reinforce learning, we implemented new practices starting spring semester 2025. Projects must choose a project management method (waterfall or Scrum). This choice is documented in the project plan and monitored by the audit team. Long-term projects are required to use GANTT charts for tracking, and all projects must use Product Backlogs or similar tools. Requiring students to follow certain methods necessitates supervision to ensure compliance. This might cause resistance and demotivate students. Thus, it is crucial that the project team finds the additional documentation helpful for their work as well.

Many students were confused about the documents they needed to submit at the end of the course. Previously, we used project closing and final report, where project teams reflected on their work and assisted the next team in starting their work more quickly. However, the titles of these documents were confusing as the project managers in continuing projects were not sure if they are required to submit them. To address confusion, we created project handover documents and reports, eliminating questions about ending documentation.

We recommended code review meetings and mob programming to enhance collaboration among the developers. Code reviews improve code quality and problem-solving and help develop reusable code. Mob programming helps share knowledge and solve complex problems together, aiding junior developers' growth. Despite recommendations, few projects use these methods, so we integrated them into our programming courses. Challenges remain as students tend to divide tasks instead of coding together.

Encouraging students to use learned methods and skills in real-life projects is challenging. Additional training helps, but sometimes requiring students to use certain methods is necessary. Support from educators lowers the threshold for using new skills. To alleviate limited teacher resources, older students mentor younger ones, especially in coding and project management.

Updating the Content of the Project Courses for Better Outcomes

To address the identified issues, we revised project-related course content, drawing on the principles of effective learning environments as outlined by Biggs and Tang (2011). Previously, many second-year students struggled with theFIRMA processes, causing extra work for teachers and the CEO and Vice CEO. We added four information-sharing sessions managed by older students, which proved very useful. The second-year students actively participated in all the sessions, and the feedback was very positive. We noticed that when students are clear about what they are supposed to do, they often deliver better results, which in theFIRMA often leads to higher quality project outcomes.

Time management is often difficult for students, who often procrastinate. We incorporated a lecture on time management and an assignment to create weekly schedules However, improvement was minimal and this part of the course needs readjustment. To address project scope issues, we incorporated scope management as a primary topic in a project-related course. This helps students understand the importance of adhering to the agreed scope, preventing scope creep and improving project quality.

These changes aim to enhance students' personal skills by teaching them in theory and providing practical opportunities, following standards 3 (Integrated Curriculum) and 7 (Integrated Learning Experiences) of CDIO framework. Despite theoretical lectures and home assignments, students do not always adapt their learning in projects.

Student Feedback

Student feedback on the ICT project courses has been generally positive. Students have reported that the revised course content effectively supports their project work and enhances their skills in both project management and various roles within the projects. They feel more confident and clearer about theFIRMA processes, which has contributed to a more cohesive and collaborative environment.

The implemented changes have also fostered improved cooperation among students, leading to further suggestions for enhancements in theFIRMA processes. The general atmosphere in the office is very positive, with students actively engaging in collaborative activities and demonstrating a genuine willingness to work together. This cohesiveness and mutual support have significantly contributed to the overall success of the projects and the learning experience.

DISCUSSION AND REFLECTIONS ON QUALITY IMPROVEMENTS

TheFIRMA's core values emphasize learning by doing, especially the CDIO standards 3 (Integrated Curriculum), 7 (Integrated Learning Experiences), and 8 (Active Learning). In theFIRMA projects, students actively engage in problem-solving, designing, and implementing real-world solutions. While the CDIO model well-implemented in software development projects, quality management often relied heavily on teachers. Our goal was to develop quality management processes that provide students opportunities to conceive, design, implement, and operate.

Educational Perspective: To achieve this, we identified challenges in theFIRMA projects and implemented changes within the CDIO framework to give students more independence. We commissioned thesis work to enhance project quality. We also adjusted project work requirements and course content to strengthen CDIO standards 3 and 7. Training sessions for second-year project courses were added, resulting in fewer questions and better integration into project work. Mentoring by older students has proven beneficial, leading to faster learning curves. Support is crucial for students to feel comfortable using new skills, so responsible teachers have their workstations in theFIRMA office.

Project Management Perspective: We required students to use either Scrum or waterfall methods for project management, with larger projects using GANTT charts. Supervision is necessary for these additional requirements, so we must be cautious given our limited resources. Enhancing project management practices included developing quality metrics and a manual, revamping the quality assurance team, and updating the project course content. Despite these changes, students do not always apply classroom learning to projects, emphasizing the need for ongoing support and mentoring.

Project Outcomes Perspective: In addition to the commissioned thesis work, we restructured the management team to enhance project quality further, and strengthen ownership, and commitment to quality management. Our experience highlighted the importance of training, mentoring, and support. We revised course content to better support students, introducing time management and scope management for second-year students. These changes aim to improve project outcomes by ensuring students are well-prepared and supported throughout their projects. The focus on quality metrics and continuous improvement processes helps maintain high standards and successful project deliveries.

FUTURE WORK

In the coming summer we will have test runs to see how well our quality metrics work. We are also developing clearer descriptions of our testing and quality assurance process to make it easier for the projects to use the services our Quality assurance team provides.

TheFIRMA learning environment is rather unique, functioning as a software company that provides services to small and medium-sized businesses within the Southwest Finland region. Establishing similar student-led project offices in other countries could significantly enhance collaborative learning and knowledge exchange. Such initiatives would allow students from diverse backgrounds to share best practices, learn from each other's experiences, and contribute to the global advancement of quality management and project development methodologies.

Future studies should investigate the impact of quality management process development on various aspects of student engagement and well-being in project-related courses. Specifically, research should examine whether these measures have positively influenced students' motivation to participate, the number of project hours completed, job satisfaction, stress levels, and perceived sense of accomplishment. Such studies could provide valuable insights into the effectiveness of quality management practices in enhancing student experiences and outcomes across diverse learning environments.

CONCLUSION

This paper has explored the strategic changes implemented to enhance quality management within theFIRMA, focusing on educational, project management, and project outcomes perspectives. By restructuring the management team, developing quality metrics and a manual, enhancing project management practices, and updating project course content, we have significantly improved the quality management processes.

The impact of these changes has been substantial. Students now have clearer guidelines and better support, leading to improved project outcomes and a more effective learning environment. The introduction of new roles, such as the Head of Operations, has fostered ownership and long-term commitment to quality, aligning with the CDIO framework.

Our experiences have highlighted the importance of training, mentoring, and continuous support. While challenges remain, the overall improvements have been positive. The focus on quality metrics and continuous improvement processes has helped maintain high standards and successful project deliveries.

In conclusion, the strategic changes in theFIRMA have enhanced quality management, providing valuable insights for other educational contexts and project-based learning environments. Through ongoing efforts and collaboration, we aim to achieve excellence in both project outcomes and student learning.

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BIOGRAPHICAL INFORMATION

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GENERATIVE AI SUPPORTED PERSONAL LIFE LEARNING ENVIRONMENT

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ABSTRACT

With the emergence of IT technologies, educational institutions have diversified their logistics in order to improve students' performance and learning quality. They invest in the implementation of learning management systems offering personalization to learners. Such personalization depends most of the time on institutions constraints. Considering this limit, the personal learning environments (PLE) represent an interesting solution for learners to develop their own learning environment. This concept fits perfectly with the lifelong learning context, which is one of the recommendations of the sustainable development goals (SDGs). However, such an environment is not necessary based on pedagogical foundations, then, we are faced with uncomfortable situations: learning not aligned with prerequisites, training layout not aligned with content and learner expectations. We developed an approach to build a PLE allowing learner to define his/her learning objectives, to build an appropriate curriculum and to follow his/her. However, the approach implementation in real context is very complex, so its generalization is essential. To overcome this, we provide an updated version of our approach using Machine-Learning algorithms and Generative AI.

KEYWORDS

Lifelong Learning, Personal Learning Environment (PLE), Generative Artificial Intelligence (GAI), Machine Learning Algorithms (MLA), Recommendations System, Standard 8.

INTRODUCTION

Nowadays, learners use different learning platforms, tools, resources to improve their skills, to acquire knowledge and to evolve in their careers. However, choosing, using and managing those heterogeneous learning artifacts can lead to an inefficient learning experience.
Regarding this situation, we have developed a PLE approach to assist learner to have a best learning experience. Our previous CDIO-contribution (Guettat et al., 2024a) introduces a method to support learners in constructing their own curriculum without the need for prior pedagogical expertise, allowing them to take independent control of their learning within a Personal Learning Environment (PLE). This approach emphasizes lifelong learning and aligns with the Sustainable Development Goals (SDGs). However, our approach is still complex to be implemented in the real world with its full potential. Therefore, we come up with an updated version, precisely an AI-enhanced version to overcome this limitation.

This paper is organized in six sections. After the introduction, we present the PLE and the lifelong learning concepts. Next, we summarize the main elements of our approach to build an efficiency PLE, the experiment results and the limitations of our approach. The next section is dedicated to our new PLE architecture based on Large Language Models (LLMs) (part of Generative Artificial Intelligence) which is an improvement of the old architecture using innovative AI technologies. The fifth section presents a prototype of our system based on this new architecture. In the last section, we conclude by summarizing our main contribution and describing our ongoing work.

PLE & LIFELONG LEARNING CONCEPTS

PLE Context

Personal Learning Environment (PLE) refers to the use of learning technologies that prioritize learner autonomy in managing tools and resources. Key questions explored include: How does the learner utilize technology to manage their own learning? What are the unique features of a personal learning environment? A PLE can be viewed as a complex activity system in coherence with the activity theory (AT) (Bal, et al., 2023; Buchem, et al., 2011).

PLE Definition, Characteristics And Objectives

“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., 2024a; Guettat et al., 2024b; Guettat & Farhat, 2017).

Based on the views of (Guettat, et al. 2024a; 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; Drachsler, 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.

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).

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), for mobile learning (Kuhn, 2017; Sharples, et al., 2005) and for learning technologies evaluation (Kuhn, 2017; Albero, 2001).

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).

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 emphasizes the value of lifelong learning and learners' motivation. 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. 2024b; 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 must assume his/her tool choices to use and contributions intended to make in learning. Therefore, we need a learner-centered learning model, which is 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. Learners in many education institutions currently use E-portfolios 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 will the learner profile be maintained?

OUR ASSISTANCE APPROACH

Overview

As part of our research in the field of PLE started in 2008, we have developed an innovative approach (Guettat, et al. 2024a; 2024b; Guettat & Farhat, 2017; Guettat, et al., 2013b) 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 "Learning objective formulation assistance", the "Curriculum generator" and the "Learning resources recommender" (Figure 1). The first component, allows the learner to define his/her learning objective without having any pedagogical experience. It's use as input the learning profile, the Bloom Taxonomy (Bloom, Krathwohl, & Masia, 1984) and the Concepts ontology, and applies to learner a dynamic questionnaire.

The second component, use the defined learning objective in the first component, and search in our curriculums repository, those matching of the learner-learning objective. We met different situations to obtain the right curriculums. From the curriculums found, we apply the Ascending Hierarchical Classification Machine Learning algorithm to recommend the best curriculum. Finally, the third component uses the recommended curriculum and using the

learner preferences and activities repository, and applies the same algorithm in the second component to recommend the best activities.

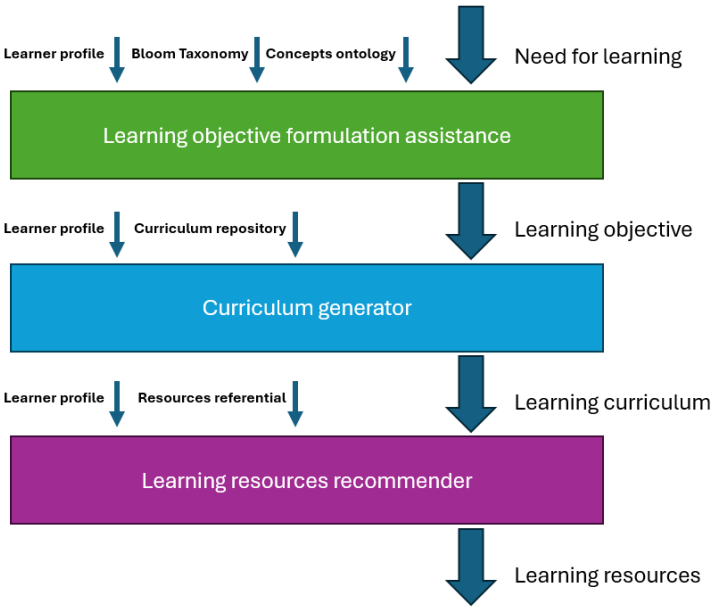


Figure 1. Overview of our Approach

Experiment and Critics

In order to verify the feasibility and the efficiency of our approach we have developed a PLE system, which allows any learner to use services offered without any technical or institutional constraints. The learner has to install a web browser extension as a frontend in order to communicate with the backend. 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 (control and experimental) according to their level. After that, the two groups invited in the same day for a test (2 hours). We asked the learners to solve the same exercise by creating their own PLE. Each learner in the control group must rely on himself to learn the concept by looking for available resource on the web and then pass the test. 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 both groups. We observed firstly the time of realization for the same activity to the two groups (Control and Experimental) (Table 1).

Table 1. Average of time activity

	Group	Number of Participants	Average (mn)	Standard deviation
Time	Control	50	~ 92	8,9122
	Experimental	50	~ 21	2,1441

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 2).

Table 2. Average of score activity

	Group	Number of Participants	Average /20	Standard deviation
Score	Control	50	8,34	5,12086
	Experimental	50	15,48	1,23485

We find that the mean of the control group is 8.34 with a standard deviation of 5.1. On the other hand, the results obtained in the experimental group are much better. Indeed, the average score is 15.5 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.

However, this experimentation shows that such a system needs a lot of development, and a huge effort to collect and manage learner profiles, curriculums repository and educational resources referential. In addition, this is even for experimentation with a limited number of participants and a very precise learning objective. An extension or even a generalization of our system is then necessary.

OUR NEW PLE ARCHITECTURE

Motivation

With the release of the ChatGPT in 2022 and then the emergence of a wide range of LLM (Large Language Model) based tools, new opportunities emerge. In addition, advances in Machine Learning open new horizons to improve existing PLE architectures. In this context, we propose an update of our PLE architecture, which benefits from new approaches and tools available today.

Related Works

The intersection of Artificial Intelligence (AI) and Personal Learning Environments (PLEs) has been the focus of various studies, highlighting their significance in promoting personalized learning experiences. (Buchem & Hamel, 2016) discuss the vital role of PLEs in cultivating essential 21st-century skills, emphasizing that personalized learning environments are instrumental in developing competencies that are crucial for modern learners. Similarly, (Almenara et al., 2024) provide a systematic review of AI applications in education, highlighting how adaptive learning environments can enhance personalization and improve educational outcomes. Furthermore, Santos & De Souza (2021) analyze the synergy between AI and PLEs, presenting frameworks and implementations that leverage intelligent systems to enrich personalized learning experiences. (Baker & Inventado, 2014; Yap et al, 2022), who detail how these technologies contribute to the creation of intelligent tutoring systems that tailor learning pathways to individual needs, also underscore the importance of educational data mining and learning analytics. In addition, (Drachsler & Greller, 2016) highlight the significance of learning analytics in deciphering learner behavior and preferences, which is essential for the development of effective AI-driven PLEs. Collectively, these works illustrate the potential of AI to transform PLEs into dynamic, learner-centric environments that support personalized and adaptive learning.

New PLE Architecture

Our new version of PLE architecture still has three components. However, they are enhanced throw the use of new AI based components (Figure 2). The first component, which is dedicated to identifying the personal learning objective, will be based on LLM (in this paper ChatGpt). Since existing LLM solutions provide configurable Rest API, it is then possible to tailor the LLM chatbot to play the role of a pedagogical expert. Then throw the learner/system chat interaction it will be possible to identify the personal learning objective.

The second component of our architecture is the curriculum generator. Gathering curriculum from the web can be done with web scraping technics. However, this will produce a huge amount of data. For this reason, we propose a decision tree model allowing curriculum matching with the fixed learning objective. Compared to our original architecture, there are at least two advantages: The first is that the curriculum does no longer needs to be described in a specific format based on a specific domain ontology and on the Bloom taxonomy; the second is related to the first one, since with no specific format constraint and with the web scrapping, the curriculum repository will be richer.

The third component is the resources recommender. Analyzing content and align it with the personal curriculum path and the learner preferences can be implemented with content-based model in machine learning like TF-IDF (Term Frequency-Inverse Document Frequency). Moreover, since in our approach we just recommend resources sorted from the most to the less relevant, it is possible to generate a summary of each content to help the learner to take the decision (Guettat et al., 2024c).

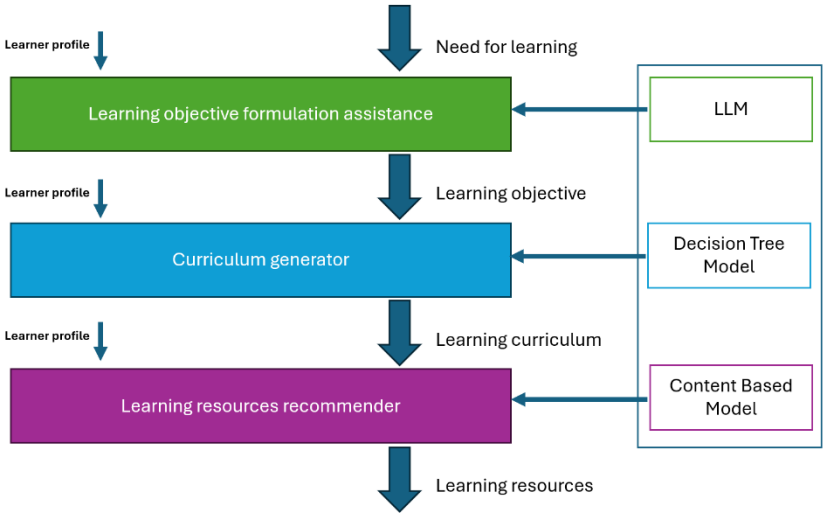


Figure 2. AI-enhanced PLE architecture

OUR NEW PROTOTYPE

ChatGpt Contributions

Our prototype is developed in close collaboration with ChatGpt 4. In advance, it was necessary to understand its philosophy and its API to make it ready to interoperate with the PLE and lifelong learning domains. Thus, we programmed its prompt by first indicating its role in our system (expert in pedagogy, mastering learning technologies), then the context (detailed specifications) and finally, we must tell it in detail the tasks it must do.

In the following, we will show in detail how we have configured this prompt, so that it can take into consideration the learner's needs in terms of defining the learning objective, generating the appropriate curriculum and recommending learning resources related to the curriculum.

ChatGpt Role

We indicate to ChatGpt, that it's an expert in pedagogy, with a long career in teaching; and master emerging technologies (AI and LLMs) as well as the related tools to assist learner in order to improve learning efficiency as well as learner performance. ChatGpt is invited to set up an assistance and recommendation system to allow a learner who is not necessarily knowledgeable in pedagogy, to build his own training curriculum after defining his learning objective; this curriculum should also contain all the appropriate learning activities to be carried out according to the learner's profile.

ChatGpt Context

As part of lifelong learning, we want to enable learner to create their own training curriculum without being an expert in pedagogy and without considering institutional constraints. Once the curriculum constructed, he/she can carry out the learning activities included in the curriculum.

To achieve all this, you are asked to assist the learner in defining their learning objective, which is made up of a concept and a taxonomic level (Bloom's taxonomy must be used), recommend the associated curriculum and finally recommend the learning activities to be carried out which align perfectly with the learning objective. Obviously, the learner's profile must be updated as the various components of the support system are implemented.

We inform you that each learner has a portfolio, initially empty, which will contain all completed, ongoing, and planned future training. Therefore, you must consider this constraint, in order to avoid the redundancy of certain activities: e.g. redoing an activity already completed and validated.

ChatGpt Process

To meet the learner's requirements, you must follow a process based on the following steps:

Step 1: Learning Objective

You must guide the learner in introducing the concept to be learned (e.g., Big Data). Based on their profile and portfolio, you should be able to recommend the appropriate Bloom's taxonomy level. The learning objective will be the pair O(c, n), where O denotes the objective, c denotes the concept, and n denotes the taxonomy level. Once the learner has validated this objective, their profile should be systematically updated.

Step 2: Recommended Curriculum

Based on the validated objective, you will need to search the internet for all learning curricula that perfectly match this objective. You must consider three situations: The first is the learning objective and the curriculum objective found coincide exactly (perfect match), the second is the learning objective does not coincide with that of the curriculum, but is part of the curriculum as a sub-objective, finally, the third situation occurs when the learning objective is not found in any curriculum; but by aggregating the fragments of several curricula, the objective in question can be retrieved.

By searching for curriculums matching the learning objective, you can find several curriculums. There, it must be able to classify them and recommend the best one. To do this, we must provide it the features and indicate which machine-learning algorithm it should use; in our case, we opted for ascending hierarchical classification.

Step 3 : Recommended Learning Activities

Starting from the recommended curriculum, you now need to recommend appropriate learning activities to the learner, taking into account the features we have defined, on the one hand, and the learner's preferences. To decide between the activities, you also need to apply a machine-learning algorithm, that of ascending hierarchical classification.

ChatGpt Tasks

The implementation of these steps can only be done by explaining clearly the tasks that ChatGpt must perform:

- Task 1: Management of the learner profile – initial training, background, possibly disabilities (myopia, deaf, blind, etc.), preferences (colors, resources, type of rapid training or not, etc.). If they have already achieved certain learning objectives, you must be able to highlight them and store them in the profile.
- Task 2: Assistance in defining the Learning Objective – You must provide the learner with the opportunity to grasp the concept they wish to learn. Once validated, the system must recommend the Bloom's taxonomy level to adopt, based on their profile. The pair O(c, n) with O: Objective, c: Concept, and n: Taxonomy level, constitutes the learning objective sought by the learner.
- Task 3: Generation of curriculums and recommendation the best that is perfectly aligned with the objective defined in the second task.
- Task 4: Generation of the appropriate learning activities that perfectly match the selected curriculum.
- Task 5: Generation of the detailed curriculum including the objective, sub-objectives, content elements of each sub-objective, activities to be carried out, recommended resources and detailed duration per activity/sub-objective and objective.
- Task 6: Update the learner profile – Everything the learner is going to do must be injected into his/her profile; the goal is to avoid repeating activities already done.

Technical implementation
The Learning Objective Component

The first thing the learner must do is define his learning objective that consists of a concept, and a taxonomic level. No more question of using a domain ontology, which must be previously designed and constantly updated. It is up to the LLM to take care of it. The concept being chosen, the learner will no longer go through the dynamic questionnaire to fix the taxonomic level he must follow. The LLM according to the profile of the learner and his preferences will systematically recommend the taxonomic level that the learner should follow. Suddenly, the learning objective (concept, taxonomic level) is well defined (Figure 3, Figure 4)

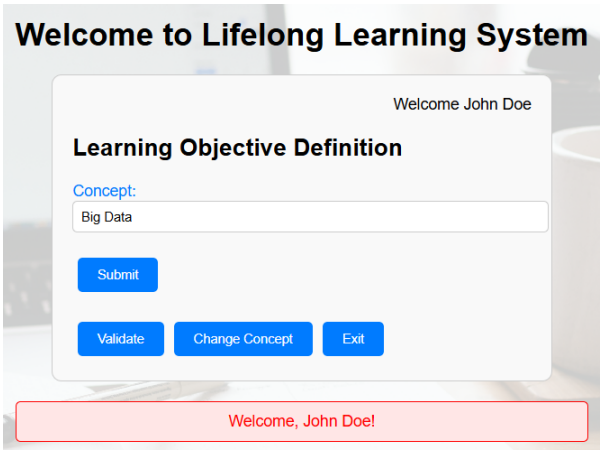


Figure 3. Concept Submitted & Validated Recommended

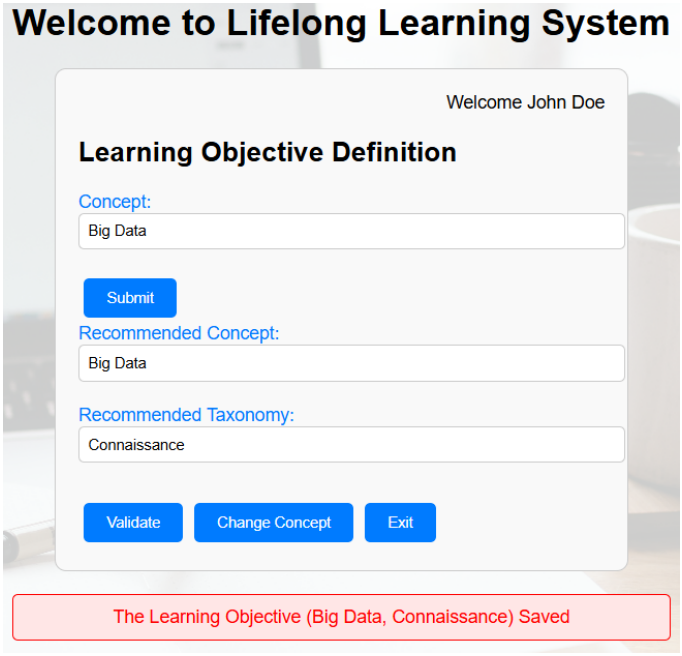


Figure 4. Taxonomy

The Recommended Learning Curriculum Component

Starting from the learning objective that the learner has just defined, and taking in consideration the learner preferences (Language, Training-type, etc.) (Figure 5), our LLM will scan on the net through search engines and using scraping techniques, to find the curriculums that match perfectly with this objective of learning. As deliverable, we have a list of recommended curriculums. Based on this list and applying an algorithm of machine learning (in our case that of the ascending hierarchical classification), the system will recommend to the learner the best curriculum (Figure 6). This classification is based on the same criteria that we have used in our previous assistance approach.

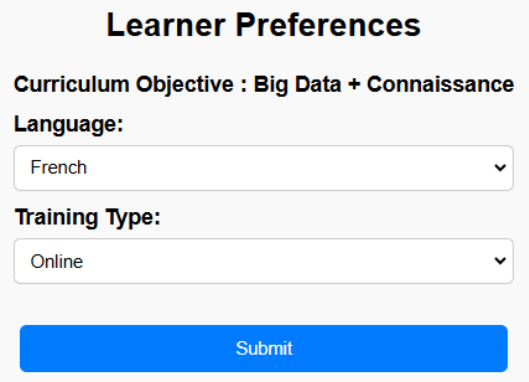


Figure 6. Learner Preferences

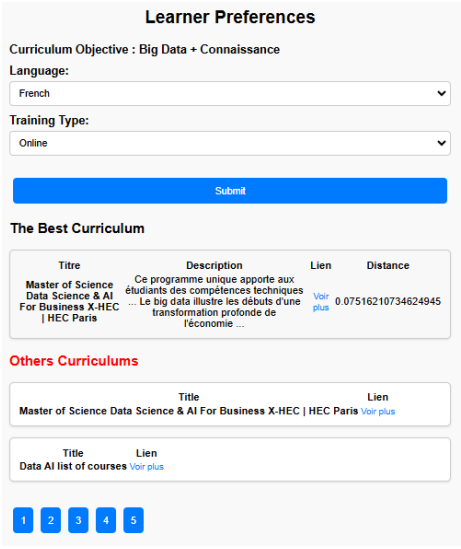


Figure 7. Recommended Curriculums

The Recommended Learning Activities Component

The curriculum being chosen, the learner must start his learning. To do this, it must carry out activities, which must comply with the objective defined and compatible with the curriculum in question. According to his profile and especially according to his preferences, and relying on the recommended curriculum, the LLM will proceed in the same way as when searching for curriculums, and will recommend the appropriate activities that the learner must carry out to achieve his goal learning. Classification criteria that are not the same compared to those used in the classification of curriculums are applied to recommend the best activities. The results obtained following the achievement of these activities will be injected into his/her portfolio and update his/her performance in his/her profile accordingly. Technically, this component is in progress.

Prototype Implementation Environment

Our LLM was powerful in the implementation of our architecture and saved us a lot of time in development. However, for better efficiency, good configuration is required to achieve good satisfaction of the developed product. Today, it is one of the most requested professions (prompt engineering). To do this, we have clearly defined and in detail the role, context and tasks of our LLM. Consequently, we have obtained a system based on backend server (Nodejs server) and a Frontend server (React Server). This system was tested locally on the practical level and the results are very encouraging: we have obtained what the deliverables we expected from it.

COMPARISON OF THE TWO APPROACHES

The table below describes a synthetized comparison between our two proposed approaches:

	The Old Version	**The New Version with LLM & AI**
System Architecture	Backend & Frontend	Backend & Frontend
Development	Lot of Effort	Low of Effort
Data Management	Relational Databases	JSON Files
Development Environ.	Heavy Environment	Light Environment
Learning Objective Definition	Bloom's Taxonomy Programming	LLM takes care of Bloom's taxonomic level recommendation.
Curriculums Recommendation	Huge effort to manage the curriculums repository.	No effort, LLM ensures the search and recommendation of the curriculums.
Activities Recommendation	Huge effort to manage and update the learning activities and resources repository.	No effort, LLM ensures the search and recommendation of the appropriate activities.

CONCLUSION AND ONGOING WORK

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. 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. We have provided an approach to build assisted PLE for learner with promising experimental results especially on terms of efficiency.

With the advancements in the field of AI, we have investigated in this paper how we can take advantages from those advancements to enhance our approach. We began by explaining the concept of PLE and its specificities. The question that subsequently arose is how to find a method that will allow the learner to create his or her own PLE. To answer this question, we have defined and implemented an approach to help learners to build their PLE. An overview of our approach, of the architecture and of the experimental results are provided.

With the advancement in the field of AI, we proposed an updated version of our approach with the integration of modern AI models. We have explained how those models can improve our approach.

We are currently working on the final implementation of a prototype as a proof of concept. The next step is to make experimentation to verify if the results will be as good as those obtained with the original system architecture. In addition, we need to evaluate the quality of the interaction between the learner and the new system. The TAM (Technology Acceptance Model) (Venkatesh & Davis, 2000) can be used for this purpose.

As perspective, we must discuss the possible shortcomings of LLM, e.g. hallucinations and compare the quality of its output to expert output.

ACKNOWLEDGEMENTS

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BIOGRAPHICAL INFORMATION

Belhassen Guettat is a Doctor, Engineer and Aggregate in computer ccience. He is a senior researcher in the LaTice laboratory (University of Tunis – ENSIT: National Higher School of Engineers of Tunis) and works on human learning environments (personal learning, personalized learning, lifelong learning), and Learning Analytics.
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Ramzi Farhat is a Doctor, Engineer in computer science, and senior researcher at the LaTice laboratory of the National School of Engineers of Tunis (ENSIT); he has supervised several master's and thesis students. He leads the laboratory's e-Learning team and has produced several scientific publications in international journals and conferences in the areas of e-Learning, Smart Learning Environments, Learning Analytics and AI in education. He has been working at this school since 2008, as a Master-Assistant and has been an expert with ALECSO since 2010. Ramzi Farhat is a certified professional trainer in Oracle Java SE 11 developer, Andela React, IBM Data Science, etc.

Syrine Karoui is a university teacher for 19 years. She joins ESPRIT School of Engineering (TUNISIA) in 2012. Her main teaching area are software engineering (Scrum Master certified), software architecture (ISAQB trainer), software testing (ISTQB certified trainer) and graph theory. She was the head of the Computer Science Department from 2018 to 2023. She's the head of the RDI team IRIS (Intelligent and Reliable Information Systems) and her research area include game theory, information security and artificial intelligence.

Oumeima Ibn Elfekih is holding an engineering degree in 2021; she joined ESPRIT School of Engineering (TUNISIA) in 2021 and today she is a teacher-trainer part of the "web" educational unit; her area of expertise is "Web Development". In addition, she is coordinator on the "Web Technologies" project. Oumeima Ibn Elfekih is in high demand by the various units and services of Esprit and has been involved in several scientific and educational events.

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TRANSFORMING TECHNICAL EDUCATION THROUGH INDUSTRY-INSTITUTE COLLABORATION ECOSYSTEM

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ABSTRACT:

The manufacturing sector in India is a significant contributor to economic development; however, it encounters with challenges such as a persistent skills lacking and a delay in the adoption of technology. This study investigates the transformative potential of an Industry-Institute Collaboration Ecosystem (IICE) in bridging these gaps by utilising the CDIO (Conceive-Design-Implement-Operate) framework at the Ramco Institute of Technology (RIT). In order to comply with the current technological and workforce requirements, the Mechanical Engineering program incorporates industry feedback into curriculum development, with a particular emphasis on CDIO standards 3, 5, 7, 9, and 10. Key initiatives include the establishment of a New Product Development Centre with state-of-the-art facilities, curriculum revisions that emphasise hands-on projects, Additive Manufacturing (AM), and automation, and experiential learning opportunities through internships and industry-led training. The research emphasises the systematic improvement of faculty competencies through seminars, certifications, and industry interactions to guarantee that teaching methodologies and technical expertise remain industry relevant. A cutting-edge framework for teaching, learning, and assessment fosters the comprehensive development of students in the cognitive, affective, and psychomotor domains. Impact analysis illustrates quantifiable advantages, such as enhanced employability, the generation of intellectual property, and compliance with the Sustainable Development Goals (SDGs). The results emphasise the significance of collaborative innovation and continuous learning competencies in equipping graduates to meet the demands of a changing industrial landscape. This work offers a replicable model for the integration of industrial partnerships into technical education, thereby fostering the development of graduates who are socially accountable, technically proficient, and innovation driven.

KEYWORDS

Manufacturing, Industry-Institute Collaboration, Lifelong Learning, Employability, CDIO standards 3,5,7,9 and 10.

INTRODUCTION

India’s manufacturing sector has shown significant potential, becoming an essential element of the nation’s economic growth. However, despite its promise, the sector faces a variety of challenges. One of the major issues is the lag in adopting advanced technologies and the significant skills gap that still exists.

The National Education Policy 2020 (National Education Policy | Government of India, Ministry of Education, N.D.)(NEP 2020) aims to transform India into a vibrant knowledge hub, marking a significant milestone for the country's education system. By bridging the gap between academia and industry, the NEP 2020 seeks to create a dynamic workforce capable of navigating and leading in an increasingly complex technological landscape.

The All India Council for Technical Education (AICTE) (Government of India, 2023) is a national-level body that plays a key role in the development of technical education in India. AICTE proposed emerging areas not only reflect current technological advancements but also emphasize the need for educational institutions to adapt and evolve. By integrating these emerging fields into the curriculum through effective industry collaboration, institutions can better prepare students for the demands of the future workforce and ensure they possess the necessary skills to thrive in a rapidly changing environment (*Government of India, All India Council for Technical Education* , 2019).

Ramco Institute of Technology's Department of Mechanical Engineering has implemented the CDIO framework and standards in the B.E., Mechanical Engineering program since 2023. As a strategic initiative to encourage industry collaboration, the Mechanical Engineering program has implemented the CDIO framework, with a particular emphasis on standards 3, 5, 7, 9, and 10. CDIO standard 3 is the integrated curriculum, which is intended to guarantee that new graduates satisfy industry standards. In the delivery of design-implementation experiences through courses that enrich the student experience in capstone design projects at Levels 1, 2, and 3, intimate engagement with industry has consistently been a crucial component (CDIO standard 5). The integration of learning experiences (CDIO standard 7) and employability enhancement programs, which encompass apprenticeships, in-plant training, professional practices, industry lectures, industry-oriented courses, and skill development courses, further solidifies the connection to the industry. Ultimately, faculty members enhance their competencies (CDIO standards 9 and 10) through close collaboration with the industry. The objective of this paper is to illustrate a collaborative experience that is mutually beneficial for academics and industry. The collaborating industries contributions are i) sharing of resources i.e human and facilities; ii) Research & Development; iii) Competency and Skill development of both students and faculty/technical staff members; iv) Academic Curriculum/Co-curriculum in the domain of design and manufacturing.

The advantages of strong relationships between academics and industry are thoroughly articulated and detailed in the literature. Siddhartha Ghosh et al. (2020) emphasised the necessity of establishing an industry-institute interaction cell to enhance collaboration between industry and academia and its resultant outcomes. Ian Bridgwood et al. (2020) proposed a framework for enhancing knowledge distribution and value generation for both academia and industry, while also advancing the engineering competencies of students. The experiences of Yong Rashidah Mat Tuselim et al. (2020) in the development of an integrated curriculum for civil engineering graduates were presented. Carmen Jaca et al (2021) presented the experiences of collaboration between university and industry through the implementation of the Project-based Learning (PBL) model. Richa Awasthy et al., 2020 proposed a framework to improve the effectiveness of university– industry collaboration (UIC). The case study of collaborative training through the industry-institute alliance is examined by Mahesh P. Joshi et

al (2022). In order to identify and implement industry-sourced CDIO initiatives in the curriculum, Soumya et al (2023) implemented a robust approach in consultation and collaboration with industry. Zeina Hojeij (2024) explored the establishment of successful UIC by conducting a review of existing literature to identify and synthesize key factors that enable collaborative innovation between industry and universities. Rosnelli et al (2024) qualitatively explored the contribution of maximizing work-integrated learning through industrial internships.

The literary review establishes industry-institute partnerships as vital to technical education reform through their ability to connect academic information with industry specifications. Studies demonstrate that joining industry with education results in better practical skill development for students who become more employable and innovative through practical education models. Researchers establish the need for curricula to align with industrial trends so graduates obtain the required competencies. Research confirms that when institutions create formal collaboration networks, they enable the exchange of knowledge which supports technology movement and advances research along with development work. Maximum effectiveness of such partnerships can be achieved only after resolving challenges that include lack of funding and inadequate industry participation and gaps in policy implementation. The study utilizes these findings to establish a framework which will explore strategies that maximize industry-institute collaboration for improving technical education results.

An investigative technique for data collection, analysis and interpretation of the role of industry collaboration in technical education was used which joined quantitative with qualitative approaches. In order to enhance the comprehensiveness of this study, the current research employs the better approaches that can be employed. Identifying the enablers was conducted through mapping the skills required in the industry as obtained in the skill gap analysis besides surveying authenticated sources like the World Economic Forum, Accreditation body guidelines and white papers of the industry. This benchmarking was conducted with respect to available global benchmarks, latest international practices in pedagogy, and acquiescence with national accreditation parameters pertaining to the course. The positive effect of these enablers was again confirmed by empirical evidence regarding their effects on learning outcomes. These models were chosen based on benchmarking other studies and case studies that have already been used in different industries. Moreover, the method adopted for assessing their need and impact offered an insight towards both the effectiveness of industrial improvements in the enhancement of technical education and the continuous improvement models as well.

BUILDING INDUSTRY – INSTITUTE COLLABORATION ECO SYSTEM

The Ramco Institute of Technology (RIT), a decade-old institution, fosters a tranquil industry-institute interaction ecosystem under the administration of the third-generation entrepreneur-owned Ramco Group of Companies. Systematic strategies were employed to establish an adaptable industrial collaboration environment that promotes the cultivation of lifelong learning competencies in students. In their first year of study, students at RIT begin their technical education with the "Student Induction Program," and in their final year, they ideally receive a high-quality placement offer in core industries or support and assistance for starting their own business as an entrepreneur. The following chapters present five strategies that RIT has adopted to build a strong industrial collaboration ecosystem, as illustrated in Figure 1. These strategies not only enhance the professional skills of students but also foster valuable connections between academia and industry. By cultivating partnerships with leading

companies, RIT ensures that its curriculum remains relevant and that students are well-prepared to meet the demands of the evolving job market.

The Memorandum of Understanding for industry-institute partnership was signed to fulfil the desirable requirement of AICTE at the Ramco Institute of Technology (RIT) in Rajapalayam, Tamil Nadu, India. This connecting was a crucial milestone in cultivating an association ecosystem between academics and industry. Systematic approaches were used to establish this flexible partnership, highlighting the cultivation of lifelong learning skills in students. Critical variables evaluated were linking the curriculum with industry requirements, including practical projects, building advanced facilities like a New Product Development Centre, and developing avenues for faculty skill development. These projects, grounded on the CDIO framework principles, provide reciprocal benefits for students and professors, facilitating the acquisition of practical insights and skills while meeting industry demands. The department level coordinator of the Industry-Institute Interaction Cell (IIIC) will regularly monitor and review the progress of the ecosystem, and the same will be discussed in department advisory committee for continual improvement. For effectiveness, a dedicated faculty is nominated each MoU-signed industry based on their specialization.

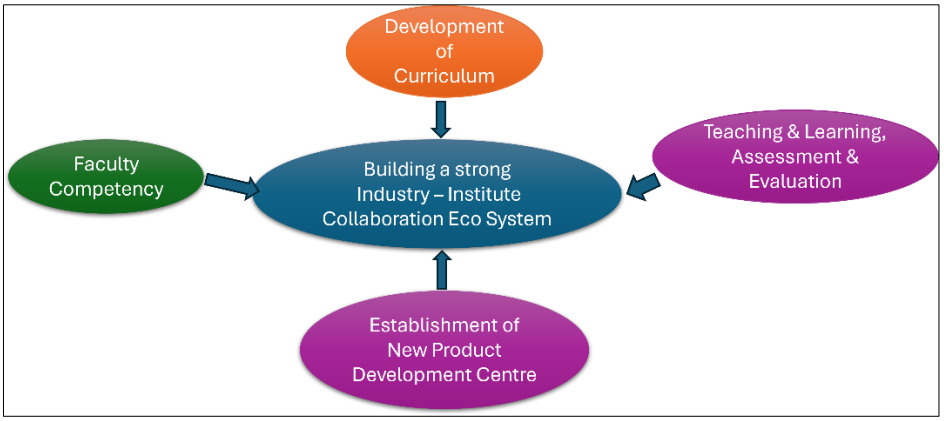


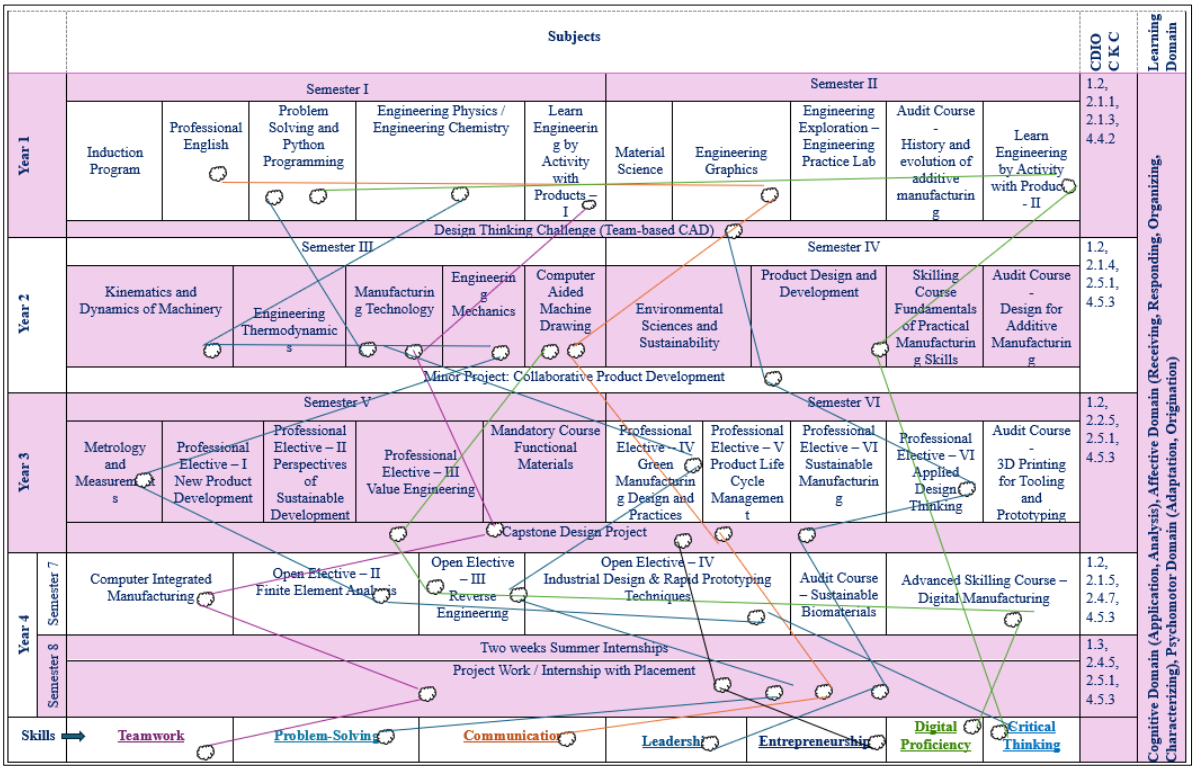
Figure 1. Strategies for building a strong Industry-Institute Collaboration ecosystem at RIT

Designing an Integrated Curriculum for Manufacturing Domain

Based on feedback from industry experts, the Department of Mechanical Engineering's program assessment and quality improvement committee conducted a curriculum gap analysis. The committee's findings indicated several opportunities for enhancement that align with current industry demands. By implementing these changes, the program aims to better prepare students for the evolving challenges in mechanical engineering. The identified curricular gaps include insufficient content in the syllabus/curriculum to address industry needs and expectations in the field of design and manufacturing, as well as a lack of exposure to the latest advancements and technological developments in courses related to design and manufacturing. To address these gaps, the program will integrate more hands-on projects and collaborations with industry partners, ensuring that students gain practical experience alongside theoretical knowledge. Additionally, updated coursework will incorporate emerging technologies such as additive manufacturing and automation, fostering a more comprehensive understanding of modern engineering practices.

The updated curriculum's primary objective is to develop a cohort of graduates who are proficient in the design and manufacturing sector, thereby ensuring that they are socially accountable, professionally skilled, and technically adept in the implementation of innovative

manufacturing solutions, in accordance with the design process proposed by Malmqvist, Ostlund, and Edstrom (2006). This includes a benefit in obtaining skills in developing technologies and contemporary practices, including virtual manufacturing through additive manufacturing technologies, fast prototyping, digital production (both subtractive and additive), 3D scanning, 3D printing, and reverse engineering. The curriculum is formulated through a cyclical process that encompasses establishing learning outcomes, aligning them, designing learning activities, and implementing assessment systems in a cohesive manner to address the dynamic requirements of the industrial sector. Figure 2 below displays a sample of the revised curriculum design process. This process ensures that students not only acquire theoretical knowledge but also gain practical skills that are essential for success in the industry. By incorporating feedback from industry stakeholders, the curriculum is continuously refined to keep pace with technological advancements and workforce requirements.



*CKC – Curricular Key Components,

Figure 2. Integrated Skill Development Pathways in Manufacturing Domain

Integrated Skill Development Pathways in the Manufacturing Domain further developed in depth skills under the concept of experiential learning. In the second year, the Design Thinking Challenge (Team based CAD) and Collaborative Product Development through minor projects were conducted. Students also had an internship and project work/internship with placement in their final year (Figure 2). In the 7th and 8th semesters, students utilized theory of various subjects at the 3rd level to solve real world problems, like: Product Design and Development, Advanced Digital Manufacturing and Industrial Design & Rapid Prototyping. In addition to the industry training, students took core disciplinary courses in the 7th semester that include Metrology and Measurements; Value Engineering; and professionalism in Product Life Cycle Management and Sustainable Product Development. Students completed advanced coursework in Project Work, Additive Manufacturing, and Advanced Skilling in Digital Manufacturing in the 8th semester (Figure 2). The combination of these courses,

supplemented by hands on learning, improved their teamwork, problem solving, communication, leadership, entrepreneurship, digital proficiency and critical thinking skills.

An analysis of the syllabus demonstrates significant knowledge deficiencies which reduce both industry-institute partnership success and graduate readiness for professional practice. Such learning gaps require attention because they could improve practical training along with interdisciplinary learning and education based on innovation.

- The training system requires better industry engagement through extended apprenticeships along with practical projects that deal with actual business scenarios.
- The educational setting fails to incorporate sufficient emerging technologies including AI and IoT with advanced manufacturing.
- Weak Interdisciplinary & Entrepreneurial Focus: Requires more cross-domain projects and startup incubation support.

Establishing New Product Development Centre

Building strong infrastructure and support for technical education enables students to more easily connect with professional skills. RIT facilitates technical education by establishing an infrastructure that aligns with CDIO standard 6: Engineering Learning Workspaces and other novel product-developing facilities (Figure 3), which are established through industry-institute collaboration. This facility supports an integrated learning environment that meets CDIO Standard 7 objectives. In addition to engineering and product development workspace, other activities like hackathons, incubation space, and partnerships with ecosystem enablers facilitate ecosystem penetration and set students up for lifelong learning. These initiatives not only enhance students' practical skills but also foster innovation and collaboration among peers and industry professionals. By engaging in real-world projects and competitions, students gain invaluable experience that prepares them for the dynamic challenges of the workforce.

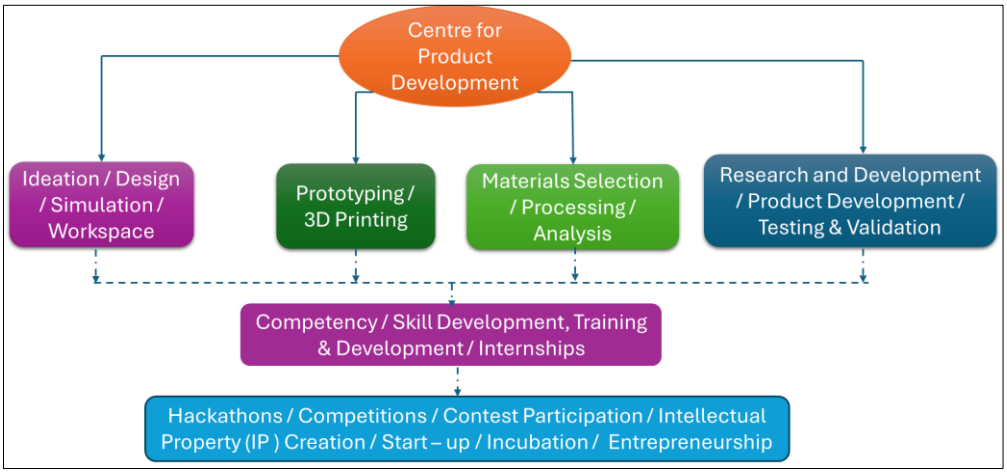


Figure 3. Integrated Workflow of the Centre for Product Development

RIT promotes the creation of cutting-edge infrastructure for the centre, encompassing 3D printing, 3D scanning, and comprehensive product development tools, with a designated area reserved just for the 3D Printing Centre. This centre collaborates with Medsby Healthcare and Engineering Solutions Pvt. Ltd. in Coimbatore, augmenting its capabilities and industry significance. Students receive intensive instruction in additive manufacturing, providing them

with the competencies required for creativity and sustainable product development. RIT equips students for lifetime learning and real-world challenges through the integration of advanced technologies, industry partnerships, and experiential learning. The Student Internship and Training Ecosystem at RIT aims to connect academic education with actual industry applications, offering students experiential learning and applicable skills. This comprehensive approach not only cultivates creativity but also challenges students to critically evaluate the ramifications of their innovations across many sectors. Consequently, graduates become comprehensive professionals, prepared to assume leadership positions in the advancing domains of engineering and technology.

Faculty Competencies

The enhancement of faculty competency at RIT is a systematic approach aligned with CDIO standards and curriculum identifiers, facilitating a cohesive strategy for skill development, research engagement, and industry collaboration. Faculty members consistently enhance their topic knowledge and teaching abilities. To enhance their technical competency (CDIO Standard 9) in manufacturing and pedagogical abilities (CDIO Standard 10), faculty members are participating in online courses in developing disciplines and certification programs from accredited universities. They are engaging in workshops and receiving training in advanced tools and approaches. This talent fosters an employability and entrepreneurial mindset, advocating for lifelong learning. Figure 4 depicts the ways for enhancing competency. These programs furnish educators with up-to-date industry information while fostering a collaborative learning environment that encourages student invention. By incorporating practical applications into their syllabi, faculty members are more effectively equipped to motivate the next generation of experts in the manufacturing industry.

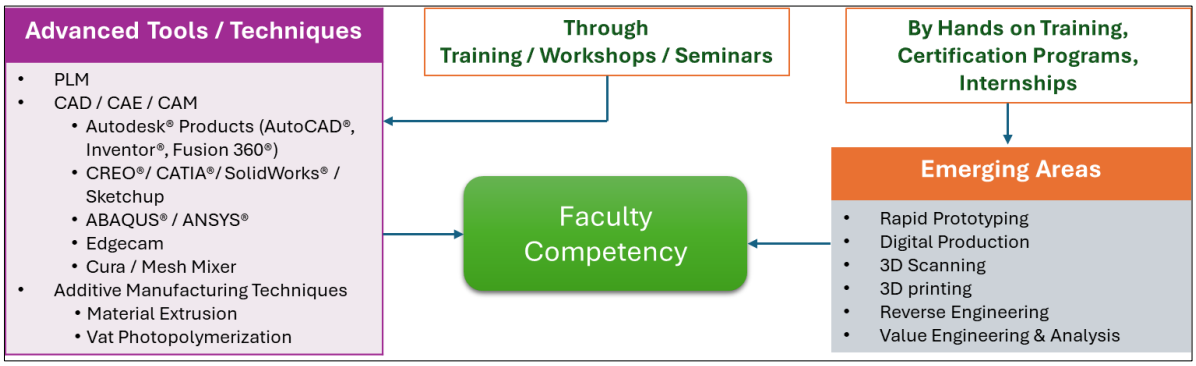


Figure 4. Building Faculty Competency for Advanced Tools and Emerging Technologies

Teaching & Learning / Assessment & Evaluation

This image illustrates (Figure 5) the interconnected framework of teaching, learning, and assessment through the Cognitive, Affective, and Psychomotor domains. It emphasizes knowledge, skills, and attitudes while categorizing engineering-specific knowledge into factual, conceptual, procedural, and metacognitive types. Formative assessments like quizzes and assignments complement summative evaluations such as exams and project reviews. Together, these elements ensure holistic development and effective evaluation of student outcomes.

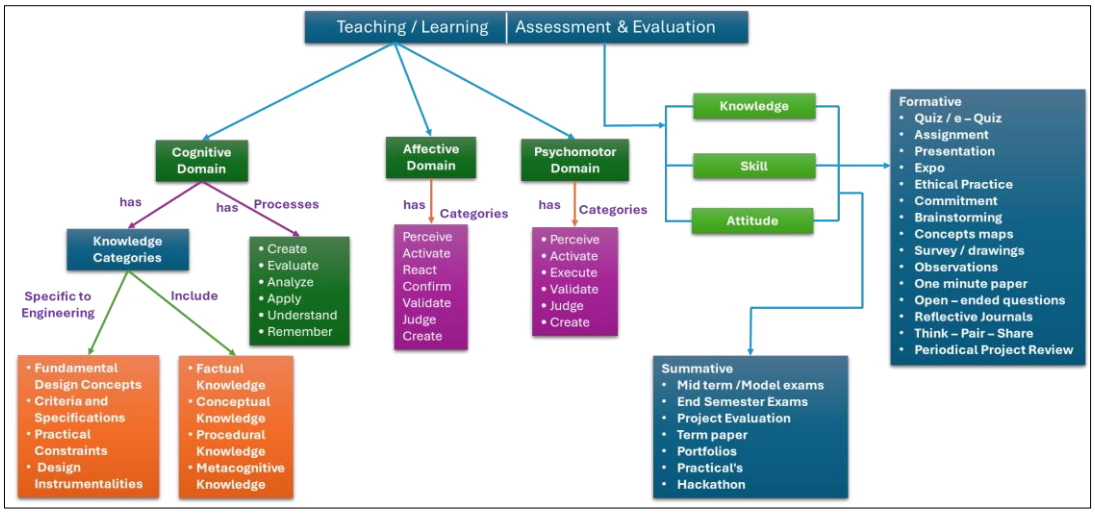


Figure 5. Teaching, Learning, and Assessment Framework in Engineering Education

The teaching-learning process for mechanical engineering integrates MATLAB® scripting and Simulink tools (Figure 6) to enhance students' understanding of key domains: design, thermal, and manufacturing. In the Design Domain, students engage in CAD Modelling, 3D printing simulations, and design optimization challenges to build their problem-solving skills. The Thermal Domain emphasizes understanding material-specific thermal behaviour, energy efficiency, and thermal gradients in AM processes, enabling students to apply these principles in practical scenarios, such as selective laser melting. In the manufacturing domain, students learn advanced techniques, post-processing methods, and sustainability practices, with a focus on quality control and hybrid part development. Case studies, such as analysing robotic arm dynamics and optimizing thermal gradients in turbine blades, provide hands-on learning opportunities. This approach fosters cognitive and psychomotor skills, enabling students to connect theoretical knowledge with real-world applications in AM.

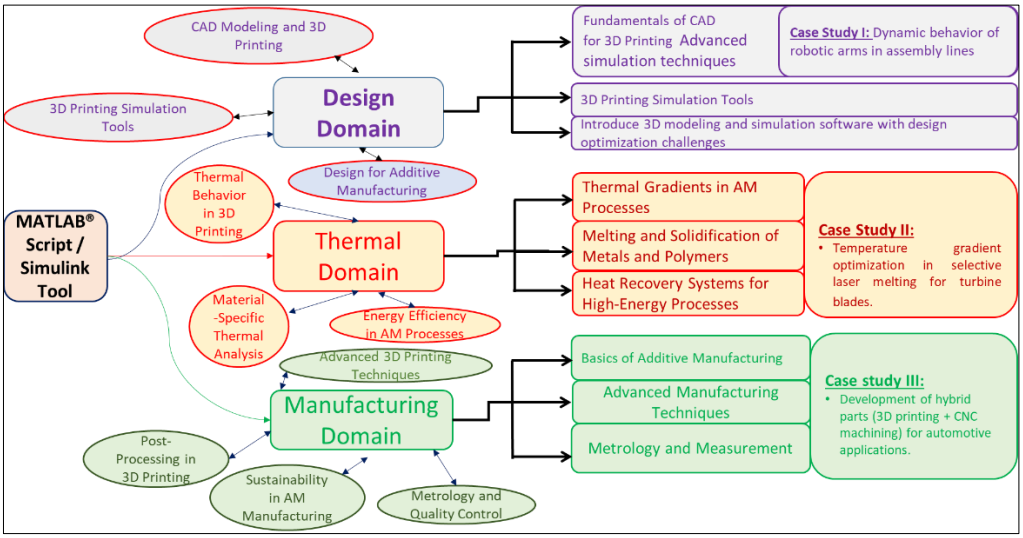


Figure 6. Integrating tool with Teaching & Learning: Mechanical Engineering Domains

The analysis of the shoulder link of a Kinova® Gen3 Ultra lightweight robotic arm connects theory and practice in additive manufacturing. Students learn how the robotic arm works and use MATLAB® FEM Tools to study how the shoulder link deforms under pressure. This helps them develop problem-solving skills by calculating deformations and analyzing how the arm responds to forces. They also practice using input parameters to optimize the arm's

performance. This activity links directly to additive manufacturing by showing how material choice, design, and production methods affect the strength and performance of parts. Overall, it helps students understand the full process of designing and making better components for robotic systems.

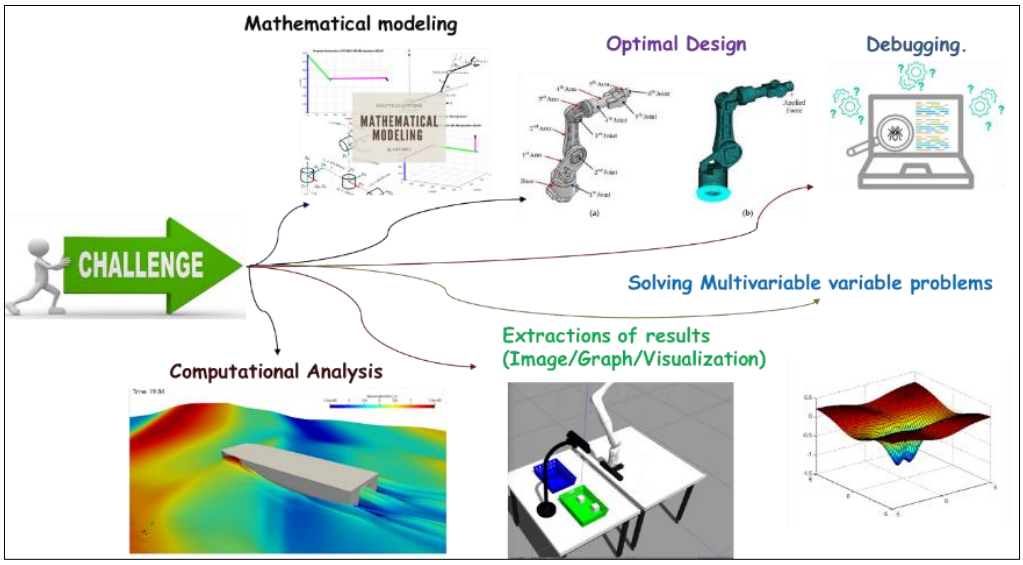


Figure 7. Engineering Challenge to Solution Workflow

The image illustrates (Figure 7) a systematic approach to solving engineering challenges, starting with mathematical modelling to understand system dynamics. It progresses to solving multivariable problems, optimising designs, and debugging for error resolution. Computational analysis is then performed to simulate real-world scenarios, and results are visualised through images, graphs, and 3D representations. This process emphasises critical thinking, problem-solving, and practical application, integrating theoretical and computational tools to address complex engineering problems effectively.

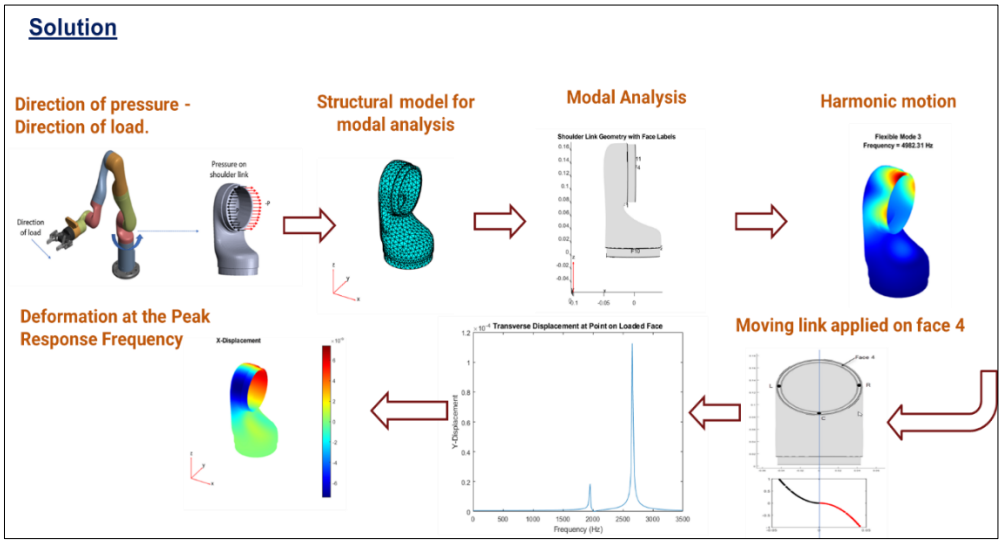


Figure 8. Engineering Problem Analysis and Solution sequence

The image outlines (Figure 8) a systematic approach to analyzing the deformation of a robotic arm's shoulder link under load. It starts with understanding the direction of pressure relative to the load and creating a structural model for modal analysis. The modal analysis finds the

natural frequencies and modes of deformation. Then, the harmonic motion analysis checks how the structure reacts to dynamic loading. The results reveal deformation patterns and displacements at peak response frequencies, providing critical insights into the link's structural behaviour under operational conditions. This process helps optimize designs for better performance and durability.

Measurement of Learning Outcome

The actual situation of the Industrial collaboration ecosystem's penetration through integrated curriculum can be judged by measuring the learning outcomes. The learning outcomes in terms of knowledge, skill, and attitude are measured through organised formative and summative examinations. These evaluations are measured with appropriate assessment instruments, such as rubrics that are tailored to the specific assessment techniques. The projects are assessed through review mechanism by evaluating the parameters (Table 1) given below:

Table 1. Measurement of Project Learning Outcomes : Meta-Skills

Online Quizzes	**Meta-Skill:** Focusing, **Sub Meta-Skill:** Sorting: Ability to categorize and relate information. Attention: Focus on key factors in design and manufacturing. **Outcome:** Develop the ability to analyze 3D printing parameters and material selection. Identify critical components in 3D printing process chains.
	Meta-Skill: Adapting, Sub Meta-Skill: Openness: Growth mindset for adopting new methods. Outcome: Apply innovative solutions and adopt advanced printing techniques in projects.
Project Work Diary	Meta-Skill: Collaborating, Sub Meta-Skill: Teamwork: Work towards shared 3D printing project goals. Outcome: Foster group synergy in design, prototyping, and final product testing.
Project Presentation	Meta-Skill: Communicating, Sub Meta-Skill: Listening: Actively understand project details during discussions. Storytelling: Explain 3D printing concepts effectively with examples.. Outcome: Interpret industry requirements and translate them into feasible 3D printing solutions. Communicate design and functional details of prototypes to stakeholders.
	Meta-Skill: Creativity, Sub Meta-Skill: Visualizing: Translate ideas into 3D printable models. Outcome: Generate innovative designs and process workflows for 3D printing applications.
Project Review (I, II & III)	Meta-Skill: Curiosity, Sub Meta-Skill: Questioning: Ask key questions to enhance project understanding. Outcome: Assess feasibility and functionality of designs in various applications like medical, aerospace, etc.
	Meta-Skill: Critical Thinking, Sub Meta-Skill: Logical Thinking: Analyze and solve technical problems.Outcome: Resolve challenges in material selection and printing efficiency for prototypes.
Viva Voce	Meta-Skill: Initiative, Sub Meta-Skill: Self-Motivation: Act independently in resolving project challenges. Decision Making: Make informed choices in design and manufacturing. Outcome: Drive the progress of 3D printing projects by self-initiating testing and optimization processes. Select appropriate materials, methods, and post-processing techniques for 3D printing applications.

This structured assessment ensures students develop technical, managerial, and ethical competencies essential for real-world applications in additive manufacturing**.**

Experiential Learning and the Problem-Based Learning approach were used to support doing different phenomena in teaching. The program targeted the mutual development of curriculum content teaching tools and training for instructors. The level of integration depended on several elements like updating the curriculum with related Program Outcomes (PO) and Program-Specific Outcomes (PSO), aligning active learning methods to Teaching-Learning Methods (TLM) and setting up faculty training to support those changes. Examinations used student performance results industry comments and faculty development progress to test these interactions.

Effective results required the establishment of Key Performance Indicators to guide efforts towards best performance outcomes. The study examined the performance of these programs in both practical results and hidden weaknesses. Students gained better job prospects and sharpened their talents as well as deeper industry collaboration which proved that improved teaching techniques bring positive changes. The transformation process experienced opposition by teaching staff along with insufficient funding tools and problems expanding the update across the entire system. The successful use of experiential learning methods in higher education depends on overcoming the specified limitations.

IMPACT ANALYSIS OF INDUSTRIAL ECOSYSTEM

The impact of Industrial Collaboration ecosystem at RIT is measured in quantitative and qualitative aspects. Some notable impacts (Figure 9) include being recognized as one of the accredited programs by the National Board of Accreditation, New Delhi; consistently generating intellectual property rights in the form of patents, copyrights, and industrial designs; developing prototypes and products through student projects; regularly interacting with industrial experts to address curricular gaps through content beyond the syllabus; designing and developing courses; and offering them in the form of skill development, emerging areas, or audit courses. These initiatives not only enhance the learning experience for students but also contribute significantly to the institution's reputation as a leader in technical education. Furthermore, the collaboration with industry partners ensures that the curriculum remains relevant and aligned with current market needs, preparing graduates for successful careers.

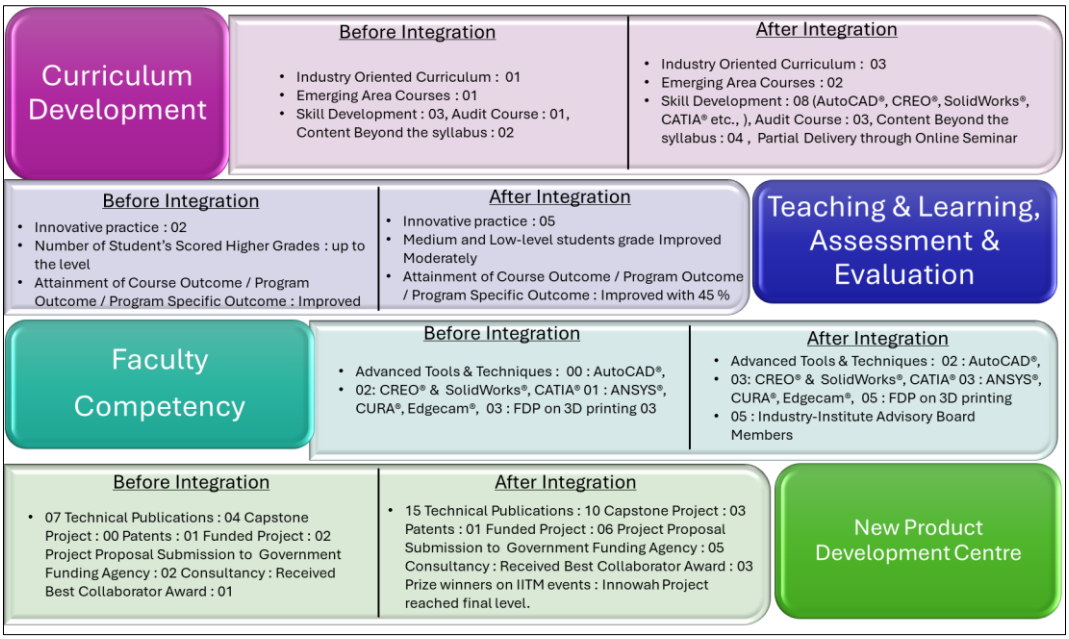


Figure 9. Impact Analysis of Industrial Ecosystem

This ecosystem in the department encourages the implementation of the Sustainable Development Goals (SDGs) and addresses societal real-time problems through industrial collaboration. Collaborated to produce joint research publications, submitted collaborative research proposals for funding, offered internships and practical training with placements, and enhanced faculty competence to fulfil the requirements and expectations of learners and other stakeholders. The department's facilities were consistently enhanced to align with industry standards. This ecosystem fortified connections with industrial partners, guaranteeing that graduates were adequately equipped to make significant contributions to society. The research presented here leads to technical education transformation because it builds strong industry-institute collaboration networks. The initiative successfully connects educational institutions to industrial stakeholders thus it improves student practical training together with academic curriculum alignment and develops technological learning experiences. Through collaborative partnerships students achieve better employment opportunities by getting practical training and relevant industry knowledge and this model speeds up research activities and tech developments. The initiative develops an entrepreneurial mindset alongside problem-solving abilities which strengthens both local and worldwide technological development of the workforce.

Some of the limitations are still experienced when it comes to the Institution-Industry Collaboration (IIC) for curriculum accreditation; this is due to the fact that the courses need to be proved relevant to the industries. There is a research gap since there is insignificant research done to establish the correlation between curriculum development, faculty training, the use of practical and valid experiences and employment placement. The prior research mainly examines theoretical collaboration models with the little emphasis placed on lived experiences. This research seeks to fill this gap by developing, trialling, and evaluating a functional IIC system where the usability of this construct in improving employability outcomes will be investigated. The findings will help to advance the best practices in matching up the curriculum to industry practices and in technology integration, benchmarking, and promoting collaborative models.

In order to evaluate the educational framework, both the quantitative and qualitative analytical tools were carried out. This was done in a quantitative manner through an assessment of

changes in students learning outcomes, skills developed as well as their overall performance. At the same time, the qualitative aspect aimed at gathering the perception of students and the experience of faculty members and industry professionals to get a better view of change implementation. Data collecting was done using pre- and post-implementation information, questionnaires to key personnel, feedback mechanisms, and performance reports. To evaluate learning effectiveness of the program, quantitative and qualitative research designs were adopted, which involved the analysis of test scores and results as well as Participant Observation research design involving the assessment of actual sessions of collaboration between the industry and students. The considerations also focused on sustaining the improvement approach to implement innovative teaching processes appropriate to the future educational system.

CONCLUSION

Technical education must experience transformation through established industry-institute cooperation systems to connect theoretical knowledge with industrial job needs. Such collaborations play an important role to develop skills while improving employment prospects together with advancing innovation efforts. A collaborative approach provides students with practical experience of actual industry problems which turns them into capable professional workers for corporate roles.

The proposed model contains structured frameworks that work together with active industry involvement and updated curricula to improve the collaboration between academia and industry. Scientifically advanced teaching environments with research methods coupled to practical learning will help technical educational organizations stay relevant to workplace changes.

The success of this ecosystem requires students to stay connected and administrators to perform regular evaluations so they can develop flexible strategies which support new technologies and industry developments. Future academic studies need to devote their efforts to establishing better collaboration models together with investigations of extended time effects and development for various engineering fields. This eco-system of industry-institute partnership creates a sustainable education system based on innovation which delivers advantage to students alongside educators and industrial representatives.

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PATHWAYS TO SUSTAINABILITY IN HIGHER ENGINEERING EDUCATION: A CONSTRUCTIVELY ALIGNED CHANGE IN FRAMEWORK

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ABSTRACT

This study explores pathways to integrate sustainability**Z** into engineering education at technical universities, focusing on traditionally non-engaged departments. The study seeks to identify strategies for institutional change through educational innovation by using Eindhoven University of Technology (TU/e) as case study. Findings offer practical frameworks to align curricula with sustainability ambitions and prepare engineers to address grand societal challenges.

KEYWORDS

Sustainability in Engineering Education, Education Innovation, Change agency, Grand Societal Challenges in Education, Standards: 1-3, 7, 11.

INTRODUCTION

Grand societal challenges, including climate change, biodiversity loss, and rising social inequalities, are exerting significant pressure on our present and future (Rockström et al., 2009; Pickering & Persson, 2020). Addressing these challenges demands a fundamental transformation in how we manage and interact with our ecosystem (Bennett et al., 2019). While technological advancement has played a crucial role in mitigating some of these pressing issues, it alone is insufficient. For technology to be truly effective, it must be integrated with societal innovation and development, creating a holistic approach that aligns human progress with environmental and social sustainability.

Higher education institutions, in particular technical universities, play a crucial role in this transformation. Technical universities not only contribute to technological development but also shape mindsets, values and attitudes of future leaders and professionals (Grek & Ozga, 2010). Around the globe, technical universities are recognizing this necessity, with Sustainability Offices expanding and diverse solutions emerging to incorporate sustainability into education. The risk is, however, that Higher Education Institutions might be adapting to the rapidly changing world too slowly. Barry and McGeown (2023) argue that most Global North universities fail to keep pace with environmental and social shifts, and are lodged in traditional ways of transmitting knowledge which perpetuates a societal system driven by economic growth and techno-fix solutions – technological responses that address societal problems without fostering systemic change.

Scholars, including Koresky and Wieczorek (2024) and Giesenbauer and Müllerchrist (2020), have sketched the scenario of a “transformative university” as an institute that enable students to become agents of change and prepares them to tackle the complex challenges we are facing as a society and where Sustainability constitutes the main rationale around which education takes place. Multiple shifts are necessary to meet this ambition, namely: (1) a shift from solving well-defined and narrow-in-scope problems, to addressing grand societal challenges; (2) from teacher-centered education to learner-centered education, where students and teachers learn from each other and co-create solutions; (3) from mono-disciplinary learning to transdisciplinary learning, where learners co-create solutions with the outside world and other disciplines. Koretsky and Wieczorek (2024) tailored this approach to technical universities, arguing that for universities of technology to become “transformative” there should also be more emphasis on the inclusion of qualitative methods (next to the highly dominant quantitative methods), focus on post-positivist and constructivist epistemologies (next to the highly dominant positivist paradigm), inclusion of social sciences in parts of the curriculum and the integration of different economic schools of thought (next to highly dominant growth-oriented paradigm). Likewise, Rosén and Leifler (2024) elaborated in their research why this transformation is particularly relevant for *engineering education*, observing the “significant gaps between current engineering capability and the needs to meet societal challenges […].” He developed recommendations based on the CDIO Standards according to engineering education philosophy and aims, curriculum development, engineering projects and workspaces, teaching and learning methods, faculty development, assessment and evaluation. The authors reflected on what the implications would be within two engineering programs (Electrical Engineering and Civil Engineering) within their respective universities – KTH Royal Institute of Technology, Denmark, and Linköping University, Sweden.

Universities, such as Eindhoven University of Technology (TU/e), have committed to acknowledging the changing world and preparing its students to address the grand societal challenges urgently requiring action (TU/e Strategy, 2018). These institutions have adopted

guiding principles to steer their actions, operations, research and education toward this overarching mission. TU/e, as a representative case study, emphasizes in its Educational Vision the goal of training the "Engineer for the Future" (Educational Vision TU/e, 2021; TU/e Strategy 2030, 2018). "Engineers for the future" are defined as T- or TT-shaped, and who are able to combine one or two disciplines with the skills to address "real-world challenges" in both science and technology. The "engineers for the future" are also "responsible", meaning they are able to recognize the impact of technology and the disruption that comes with it "toward a future that works for all of us" (TU/e Strategy 2030, 2018).

Education at Eindhoven University of Technology is structured around nine departments. Previous research (Roefs, 2024; Rijsdijk et al., 2024) suggests that the vision outlined above resonates greatly with three out of nine departments. The input, collected amongst students and teachers, (Roefs, 2024; Rijsdijk et al., 2024) propounds that some research and education areas are more "suitable" to appeal to this visionary approach of Sustainability implementation and Grand Societal Challenges orientation rather than others. Students and teachers fail to see the connection between their degree program and Sustainability, or identify other important barriers that hinder this implementation. Other barriers involve lack of professional knowledge, skills or attitude to teach about Sustainability or lack of time to properly integrate the topic within the seven weeks of time that most courses within TU/e are allocated.

Problem definition and research objective

While universities increasingly acknowledge their evolving role in society and their potential to empower students as agents of change to tackle current and future sustainability challenges (Scholz, 2020; TU/e Strategy, 2018), a gap persists between these ambitious mission statements and the practical actions implemented in education. Within our university, TU/e, some departments overlook how their work connects to Sustainability or simply lack the tools to integrate it in their educational activity (Roefs, 2024).

Especially within the engineering discipline, all subjects have a direct relation with Sustainability, in this research I aim to provide educators with guidance, and a layered approach to Sustainability integration in engineering education, prioritizing departments that have less affiliation with Sustainability. The outcomes outline actionable changes in the Constructive Alignment (CA) framework, further explained in the theoretical section of this paper.

Research Questions

This paper seeks to answer the following main research question:

What pathways can educators within department of technical universities that traditionally do not engage with Sustainability undertake to incorporate it effectively into their educational program?

The following three sub-questions will help guide the response to the main research question:

1. How is the current engineering education organized?
2. What are the pathways to sustainability integration within an educational context?
3. How can the implementation of Sustainability be operationalized in practice?

METHODS AND RESEARCH DESIGN

This research adopts a **constructivist** worldview, a prevalent approach in qualitative research. Constructivism is used in instances of theory generation, considers social and historical construction, and is grounded on the ontological discourse accepting the coexistence of multiple realities (Cresswell, 1994). While the framework of this research is constructivist, it is anticipated that interviewees might approach reality from a postpositivist perspective. However, as outlines in Table X, these interviews will be analyzed though a constructivist lens to match the methodological approach of this research. In order to cater to the constructivist approach, case study is adopted as a methodology as it enables to focus on contextual understanding as well as the gathering of rich detailed data (Creswell & Poth, 2018). Semi-structured interviews also cater to the constructivist worldview adopted in this research as their outcome provides space for interpretation of findings, and leads to a form of analysis, through coding, that allows the identification of patterns.

TU/e as a case study

We employed a case study methodology, selecting Eindhoven University of Technology (TU/e) as the focal institution. The primary reason for this selection is TU/e's strong emphasis on educational innovation, exemplified by initiatives such as TU/e innovation Space, the center of expertise for Challenge-Based Learning, and its focus on entrepreneurial education. These initiatives align closely with the objectives of this study, providing a rich context for exploring education innovation toward sustainability.

In addition, the researcher's role as a Sustainable Education Development Officer at TU/e greatly facilitates the study. This position has enabled the development of a robust network of teachers and support staff over the past year, offering access to key stakeholders and data sources.

To further validate the findings, we plan to present these at June 2025's CDIO international conference, engaging with an international academic audience to gather diverse feedback and assess the broader applicability of the conclusions.

Action research

Action research is a participatory and iterative methodology employed in this study due to its focus on educational settings, and its features linked to engagement, participation and collaboration (Kemmis & McTaggart, 2000; Coghlan & Brannick, 2014).

Preliminary data collection

Semi-structured interviews

During the academic year 2023-2024, 25 semi-structured interviews were conducted with teachers at TU/e from six different departments. These interviews have been carried out following an analysis of elective courses offered at TU/e and their description on Osiris (platformed used at TU/e to elaborate on the course offer). The 25 interviews have been used as source of data in Roefs' Master's thesis (2024), yet they also provided in-depth insight on the general orientation of different departments toward sustainability integration and transformative educational practices.

Student survey

In addition to the semi-structured interviews, 108 responses across all nine departments of TU/e were collected by bachelors and masters students (Rijsdijk, 2024). The inquiry was

collectively designed and distributed between TU/e's GO Green Office and TU/e Sustainability Office. Respondents were surveyed on their perception of the relationship between their study program and sustainability. They were also asked about the inclusion of transformative education practices in their learning, which involve alternative pedagogical techniques designed to facilitate systemic thinking, the acquisition of a plurality of worldviews, and a sustainable rationale (Roefs, 2024). Similarly to the teacher interviews, these responses were also used to assess the positioning of different departments concerning transformative educational practices and sustainability integration.

Focus Group Sessions

Within the same academic year, three departments within TU/e (innovation Space, Sustainability Office and Academy for Learning and Teaching) collaborated to organize three sessions attended by education developers, teacher supporters and educators. The sessions covered: (1) best practices of sustainability integration at TU/e; (2) barriers and promises of implementing sustainability in education; (3) promotion of sustainable partnerships in transdisciplinary education practices to provide a broad understanding of complex societal challenges. These sessions provided a broad understanding of the current state at TU/e and allowed data collection through a randomized data collection strategy.

Planned data collection

In addition to the data collected prior to this submission, we plan to conduct additional interviews with specific target groups within the university. While the first round of field study assessed transformative and sustainable practices across departments, the next round of semi-structured interviews will focus on departments traditionally disengaged from Sustainability practices. Interviews will take place with teachers and students and program directors.

Observations will continue throughout the study. The role of the researcher within TU/e, meetings, provides opportunities to collect additional input during meetings, co-creation sessions, and informal exchanges with colleagues.

Sampling Strategy

Interviews with teachers, responses from the students and the analysis of the courses offered university-wide, enabled us to map the degree to which different departments of TU/e are open to the integration of Sustainability in education, as well as alternative pedagogies that would enable a more integrated approach to Sustainability. Out of nine departments at TU/e, only three departments showed convincing evidence on the degree of current implementation of Sustainability practices in education, these departments being Industrial Engineering & Innovation Sciences, the Built Environment and Industrial Design. The departments of Applied Physics, Mathematics & Computer Sciences, Biomedical Engineering, Chemistry & Chemical Engineering, and Biomedical Engineering, on the other hand, showed some examples of

innovative practices in education, yet still neglect the relation between their study program and Sustainability.

Teachers and education developers within the latter group constitute the target group of this study, as the traditionally-non-engaged departments referred to in the main question.

Mapping faculty members (students and teachers) across different departments revealed varied levels of engagement with Sustainability and educational innovation. This mapping exercise will be elaborated upon in the final paper.

Table 1: Summary of data collection and data analysis.

Problem	***Research question***	***Data (what?)***	***Source (who?/where from?)***	***Analysis (how?)***
The way that current engineering education is defined in non-engaged departments is unexplored, and might not mirror universities' missions statements of preparing future engineers of addressing grand societal challenges.	**How is current engineering education of non-engaged departments characterized?**	Mapping of the current institutional logic of TU/e.	Semi-structured interviews (Teachers, Students, Education Directors, Education Board)	In-vivo coding (Atlas.ti) Find patterns, similarities and differences within interview transcripts
It is unexplored in research how pathways of institutional change translate to an educational context, and whether this theory resonates with teachers and education developers involved in education design.	**What are the pathways to sustainability integration within an educational context?**	Pathways (way of achieving a determined result – sustainability in education)	Transition studies literature, educational science literature. Validation workshop.	Analysis of input collected through literature and validation workshop.
Educators of non-engaged departments fail to see what the implementation of Sustainability in Education practically implies as there seems to be little to no guidance.	**How can the implementation of Sustainability be operationalized in practice?**	Immediate actions on the constructive alignment framework.	Workshop/working group session with education designers and policy advisors. International validation workshop.	Thematic analysis of the input provided during the working group or workshop.

One validation workshop will be held with experts in the international context during the CDIO conference taking place at Monash University in June 2025.

The table below summarizes key data collection and data analysis moments taking place throughout the research endeavor.

THEORY

To address the question we combine transition studies, new institutional theory, and educational insights as this relation permits us to study change within education institution, and to determine implementational insights in practice within a degree program.

Regimes

Regimes are dominant and highly institutionalized socio-technical structures that undergo constant negotiation (Fuenfschilling & Truffer, 2014; Fuenfshilling & Binz, 2018). Actors (parties within the socio-technical structure), technology (the infrastructure alongside which the actors operate) and institutions (rules of the game), constitute the basis of any regime (van Summeren et al, 2023).

In our case, the Higher Education system can be defined as a regime since it is built around the interplay between actors, institutions and infrastructure. Within the Higher Education system, actors include teachers, students, academic and non-academic staff and the education and research partners. Higher Education Institutions' technology is represented by the infrastructure that enables learning and education, namely university campuses, classrooms, online platforms and other learning ecosystems. Lastly, higher education institutions are characterized by the rules of the game that legitimize education. At present, education is built around Intended Learning Objectives (ILO's) for the educational path, and a series of Learning Activities (LA's) that facilitate the process of learning. These ultimately culminate in Assessment (A) which provides to acquire study points or standardized European Credit Transfers (ECTs). The cumulative sum of these allows students to earn degrees or diplomas, currently the only recognized proof of education completion.

New Institutional Theory

To transition from the old regime to the new desired regime, where Sustainability is implemented within education, *Institutional Work* is needed. Lawrence et al. (2011) identify practices to create, maintain and disrupt institutions. Integrating Sustainability in education involves institutional work to change the old regime and transform it into a new one. As Lawrence et al. (2011) suggest, multiple *pathways* exist to facilitate this transition: (1) *Maintaining* is part of institutional work, does not imply any transition, yet reinforces the idea that maintaining institutions requires institutional work likewise. As a matter of fact, Trank and Washington (2009) identify actions of valorizing and demonizing, mythologizing, and embedding and routinizing as processes to maintain an institution, which are required once the change is adopted. (2) *Creating* implies the creation of new space to facilitate new regimes to exist. Lawrence and Suddaby (2006) emphasize the importance of specific actions in institutional work to create new regimes. These include advocating, defining, and vesting. Advocating involves actively mobilizing political and social support to push forward new institutional structures. This includes lobbying for curriculum changes or persuading key stakeholders to adopt sustainability principles in educational frameworks. Defining entails establishing clear rules, norms, and boundaries that give the new institution its identity and purpose, such as creating frameworks for sustainability-focused programs or criteria for courses. Vesting refers to granting legitimacy and authority to the emerging institution, such as formalizing new sustainability guidelines within accreditation standards or establishing governance structures to support these changes. While maintaining is a crucial avenue to support existing institutions that need to be endured, and creating offers a launchpad to pilot new intentions aimed at facilitating sustainability transitions, this paper focuses on the (3) disrupting pathway. Disruption involves revising and altering the old system. This alteration

results in three distinct avenues ranging in levels of less to more radical. Sterling (2004) identifies the following three practices: (a) accommodation, where Sustainability is seen as a "gloss" or as an "add-on" (Lönngren et al., 2022). Small changes are made within a curriculum to "free space" to accommodate Sustainability integration, for instance, in the form of a guest lecture; (b) *reformation*, which implies more significant changes, aimed at dismantling current educational practices, but without altering the entire regime, thus the interplay between actors, technology and institutions; (c) *transformation*: a complete reimagining of education's purpose, incorporating systemic changes. Researchers such as O'Sullivan (1999), Giesenbauer and Müller-Christ (2020), and Rodríguez Aboytes and Barth (2020) have explored transformative education, its goals, and the practical implications of such a shift.

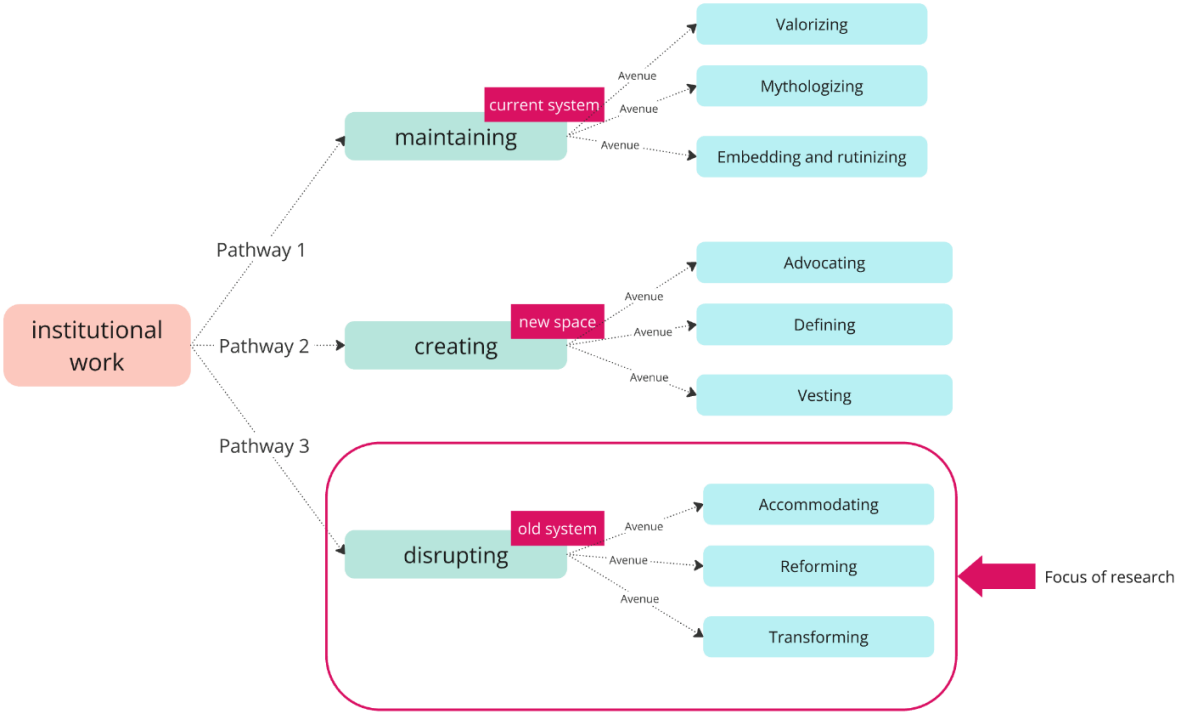


Figure 11: Theoretical background of research

The Constructive Alignment Framework

In his work, Biggs (1996) brings together literature on constructivism and instructional design. Constructivism is a family of theories that explain how individuals create meaning focusing on the learner's perspective. Biggs synthesized these two bodies of literature by identifying the way that best works for learners to make meaning – namely, by following a design that constantly seeks alignment within its main components, defined as the Intended Learning Outcomes (ILOs), Learning Activities (LAs) and Assessment (A). This framework is commonly recognized as the Constructive Alignment (CA) framework. As Loughlin, Lygo-Baker and Lindberg-Sand (2020) revised the framework, they noted that it has remained relevant over time, and that the current education system is still largely administered around this framework. Despite its longevity, literature does not challenge its validity. This consistency explains why it is used as a foundation for this research.

Analytical framework

In this paper we combine the insights of regimes, institutional theory and Constructive Alignment to develop a comprehensive analytical framework. Figure X shows that is necessary

to perform institutional work in order to transition from an old regime to a new regime where Sustainability is fully embedded in the education of traditionally non-engaged departments. The figure also shows that multiple pathways are, in fact, possible in order to reach the desired state.

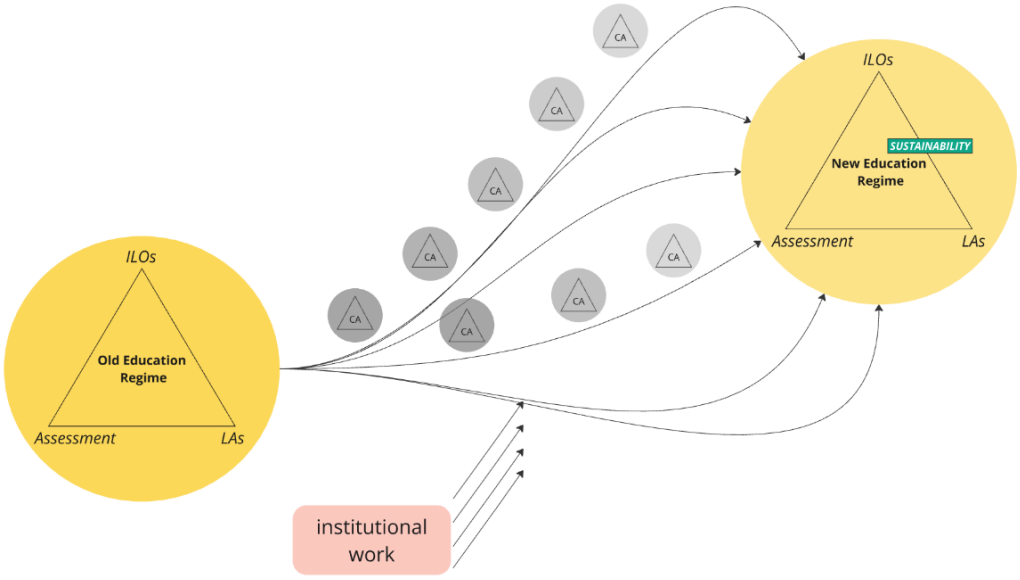


Figure 12: Theoretical framework: Institutional Work to encourage a transition from the olde education regime to the new (desired) education regime.

Next steps

Building on the findings from interviews, surveys, and focus group sessions, the next phase of this research will focus on deepening insights into departments traditionally less engaged with sustainability, identified during the preliminary steps. Additional semi-structured interviews will be conducted with educators, students, and program directors to identify specific barriers and opportunities for integrating sustainability into their curricula and how these can be mitigated by means of *institutional work*. Observational data collected during co-creation sessions and discussions with stakeholders will further enrich the analysis. To validate the proposed pathways for sustainability integration, a workshop will be conducted at the CDIO international conference, engaging an international audience of educators and policymakers. This collaborative session will refine the practical frameworks developed in this study and assess their broader applicability across technical universities. **The outcome of these activities will result in a completion of the framework proposed hereby, where different pathways of institutional work are connected to concrete changes within the Constructive Alignment framework**. Finally, the research will aim to synthesize these findings into actionable recommendations for institutional change, emphasizing strategies for aligning engineering education with sustainability goals and the addressing of grand societal challenges.

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THE TYRANNY OF NUMBERS: WHY MARKING CDIO ACTIVITIES COULD BE DIFFICULT

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ABSTRACT

This paper offers a reflection on how traditional marking methods frequently fail to capture the deep learning students can achieve when involved in CDIO-inspired activities. Active learning activities and projects offer opportunities to learn discipline content, technical skills and graduate capabilities like communication, teamwork, conflict management, and social responsibility. Including all the possibilities in a list of learning outcomes is challenging. And since in a constructively aligned course the sole purpose of assessment is to measure the attainment of the learning outcomes, much learning frequently goes unrecognised. Most educational institutions use numbers to "measure" students' achievement but, what do these numbers really mean? This paper argues that numbers are very blunt instruments to measure the learning students achieve when involved in projects, and calls for more qualitative, student-driven approaches.

KEYWORDS

Qualitative Assessment, Project-Based Learning, Standards 2 and 11.

INTRODUCTION

Since its inception in the year 2000 the CDIO framework has effectively supported universities responding to the challenges and requirements of the 21st century, as outlined in ABET's (Accreditation Board of Engineering and Technology) expectations for graduating engineers (ABET, 2025). Many institutions around the world, members and not members of CDIO, are adopting teaching strategies that are student-centred, open-ended and focus more on the process than the product. Consequently, students' learning has broadened, i.e. along with discipline specific information, they are learning skills and competencies that are sought after by employers. Today, most graduates leave university ready to work and contribute immediately after they complete their program[1].

In many cases, the rapid diversification in teaching activities is still unmatched by improvements in assessment methods. To respond to Covid challenges some universities started a move from the Assessment of Learning to Assessment for Learning, and finally to Assessment as Learning (Yang & Xin, 2022), but many institutions are still 'stuck' in the assessment of learning model. At individual level, many academics prefer the use of quantitative assessment methods to mark students' work. They use tests and rubrics to produce a number that reflects the student's competency (knowledge and skills) in the subject. Numbers are useful and have a place, but much of what students learn in projects and other active learning experiences is difficult to capture using quantitative assessment methods. The problem arises because learning outcomes (LO's) cannot capture the whole spectrum of what students learn while working in teams to complete projects, and in a structurally aligned course assessments only evaluate the declared LO's (Biggs, 2014).

The following sections present some reflections about the role of universities in today's world, followed by a brief outline of constructive alignment to highlight the importance of aligning assessments to learning outcomes, then some comments on the use of quantitative and qualitative techniques to assess students' work, and finally some suggestions on how to transform assessments to capture more of what students learn in CDIO-inspired activities.

WHY DO STUDENTS GO TO UNIVERSITY?

Before the introduction of online repositories of information like IEEExplore, Google, Wikipedia and YouTube, students came to university looking for information. Books in libraries contained the information students needed to become doctors, lawyers and engineers. Professors were the "sage on the stage" whose role was to make information in books more accessible to students, with different levels of success. Lectures were not recorded, hence there was no need to make attendance compulsory, students wanted to attend because if they skipped a lecture, it was their responsibility to find the missed information on their own, in a book or a classmate's notes.

With the advent of the internet in the 1990's, information is no longer confined to books and libraries; it can be accessed anywhere, any time and in various formats. Hence students no longer attend university to acquire information, they now come looking for experiences. Furthermore, the amount of information in every discipline is continuously growing, making it impossible for universities to teach students everything they will need to succeed in their

[1] In this paper the word *course* will be used to refer to the collection of activities and assessments involved in the delivery of a subject. Courses are called or subjects in different institutions. The word *program* will be used to refer to the collection of courses that a student must complete to graduate. Programs are called courses or degrees in different institutions.

careers. Content must be carefully curated and delivered. The role of teachers has gradually shifted to become a “guide on the side”, helping students develop skills to find, classify, and use information to solve problems (Christersson, 2019).

From an ontological perspective, students come to university to ***become*** engineers, or doctors, or architects. After graduation engineers do not say “I do engineering”, they say “I **am** an engineer”. A big part of the role of educators should be to facilitate this transition, but how? Students become professionals by adopting the distinctive behaviours of the profession. A good engineer is not only knowledgeable in Physics and Mathematics but is also expected to be a good problem-solver, communicator, team member, resourceful, disciplined, responsible and a long et cetera. To what extent are university programs designed to purposely develop all these skills in students? Programs need to provide opportunities for students to practice the behaviours of their profession and reflect about their transformation. Academics must be role models, projecting the behaviours they want their students to adopt (Barbarà-i-Molinero, 2017).

In this context, assessment needs to shift its focus from content to skills, and from product to process to be more effective. It needs to shift from quantitative approaches (numbers) to more qualitative techniques (statements).

CONSTRUCTIVE ALIGNMENT

Constructive alignment is a teaching method that focuses on the learning outcomes students achieve, rather than the topics taught. It draws on constructivist learning theory, which assumes that students construct their own knowledge (McLeod, 2024). The process to design constructively aligned courses follows these steps (Biggs, 2014):

1. Define learning outcomes. Bloom’s taxonomy (Bloom, 1956) is frequently used to describe the level at which students need to demonstrate the learning outcomes.
2. Design learning activities to support students’ attainment of the LO’s. This involves the matching of topics from the syllabus with activities where students learn from what they do, not from what the teacher does (active learning) (Bonwell & Eison, 1991).
3. Design assessment tasks to evaluate if the LO’s have been achieved. Assessments must give students opportunities to demonstrate what they know and can do, focusing on the high levels in Bloom’s taxonomy.
4. Reflect on student performance and review LO’s if necessary. Start again from step 1.

In theory, a properly aligned course ensures that students engage in learning activities that will help them achieve the desired outcomes while supporting teachers creating a learning environment that supports students' learning. However, in practice learning outcomes fall short at capturing all the learning that can occur when students engage in CDIO-inspired learning activities like project-based learning and role-playing. Much learning goes unnoticed and ignored because it is not part of the stated learning outcomes and therefore it is not assessed.

QUANTITATIVE AND QUALITATIVE ASSESSMENT

The CDIO framework is a good guide to design activities conductive at attaining Bloom’s high levels of learning behaviours. However, appropriate assessment methods need to be chosen to effectively capture and evaluate students’ learning, even when this learning is not part of the official course learning outcomes.

Quantitative assessment is good to evaluate Bloom's taxonomy lower levels. Multiple-Choice Questions, short answers, and use of formulae are examples of assessments that evaluate students' ability to retain and recall information. Since only one correct answer is possible, these assessments are generally easy to mark. In some instances, automated marking is possible (and recommended).

Numeric results are very useful to rank students and create reports but, how accurately do they reflect student learning? What does it mean that a student achieved 75% in teamwork? Did they complete 75% of their work? Did they attend 75% of the meetings? Did they contribute 75% of ideas? When designing quantitative assessment artifacts, it is important to keep in mind all the learning that remains unrecognised.

Open-ended projects, problem-solving in teams, conceive, design and implement artifacts to meet specific requirements are examples of activities that help developing Bloom's higher learning behaviours. Qualitative instruments like reflective statements, surveys with Likert scale questions, interviews, and focus groups are good to evaluate Bloom's high levels.

However, there are challenges: these instruments are more difficult to design, it takes longer to complete the marking, and assessment is usually subjective. Rubrics can support qualitative assessment, but they must be designed with care to avoid students working to the rubric, instead of focusing on the overall process.

Ideally, both quantitative and qualitative assessments should be used to obtain a good grasp of students' progress. Quantitative approaches are better suited for assessing performance, while qualitative approaches provide more valuable insights into the student's developmental processes.

One example of project-based learning is the "Crazy Machine" Project (CMP) electrical engineering students complete in the third year of their program. This project was presented at the CDIO conference in 2013 (Maynard and Ortega-Sanchez, 2013). The project is so successful that it has remained practically the same over the years. Student feedback consistently reports high satisfaction levels, for example one student declared during an interview at the end of semester: "I really enjoyed [the Crazy Machine Project] because I have developed so many different things like technical skills or working with a team or spending time problem-solving things. It was a really good project all around".

In its current edition the Crazy Machine project is assessed with the following submissions:

- **Progress report** (25%). Submitted at the end of week 6 of semester.
- **Crazy Machine video** (25%). Produced by the team to describe the design process and implementation and testing of their machine. An example is available in this link.
- **Crazy Machine demonstration** (20%). On the last week of semester students explain and demonstrate their machines.
- **Final report** (30%). Submitted at the end of semester. Formal report covering the design process including Conception, Design, Implementation and Verification of the machines.

Additionally, students submit a video where they declare, to the best of their ability, all the learning that took place during the development of the CMP. Self-declared learning is possibly the most valuable kind of assessment, and it rarely matches well with the course learning outcomes.

SUGGESTIONS TO IMPROVE THE ASSESSMENT OF CDIO-INSPIRED ACTIVITIES

Any discussion about assessment must take place in the context of the learning outcomes. To discuss changes in assessment it is necessary to start by reviewing and changing, if necessary, the learning outcomes. What students can learn in hands-on, practical courses is very broad and varied. Most likely, each student learns different things from completing the same activity.

To support the construction of useful learning outcomes, they could be classified into at least two categories: essential and desirable. Essential LO's are those that all students must achieve. These are non-negotiable and failing to demonstrate any should result in failing the course. It is recommended that each essential LO is explicitly stated in at least one of the course learning outcomes.

Desirable learning outcomes are those that some students may attain while others do not. These outcomes can be amalgamated into abstract categories like communication skills or social responsibility which encompass a big number of skills and competencies. Declaration of learning is the most effective way to capture desirable learning.

Once the CLO's have been established, assessments should focus mainly on essential LO's while leaving room to include desirable LO's. The use of rubrics is highly recommended to evaluate the attainment of both essential and desirable LO's. A good rubric uses levels of achievement rather than numeric scales to evaluate students' work. For example, an item on communication skills could be evaluated as 'developing', 'competent' and 'proficient'. A description of what each category means must be shared with students as the minimum amount of feedback they can receive. These descriptions should provide information that helps students understand what abilities they need to develop to improve their performance.

The following list shows the LO's of the course where students complete the CMP:

1. Describe and implement digital systems using VDHL and FPGAs.
2. Use commercial Field Programming Logic Device development tools to implement embedded systems.
3. Explain and apply the Universal Design Methodology (UDM).
4. Work as part of a group to develop a project
5. Report your experiences in an orderly and effective format.

All learning outcomes in the list are essential, i.e. every student is expected to demonstrate their attainment to pass the course. Rubrics are extensively used to let students know the expectations.

The importance of the student voice

To deal with the facts that learning is individual and that after completing an activity each student will learn different things at different levels of understanding, assessments should provide opportunities for students to declare their own learning. Reflective statements, surveys, videos and interviews are excellent vehicles to capture students' self-declared learning. This is the kind of learning that will possibly stay with students for the rest of their lives and very frequently passes unrecognised.

In assessing student's self-declared learning, it is important to keep the following question in mind "to what extent did the student use this assessment to demonstrate they are becoming the best possible engineer/lawyer/architect/doctor they can be?". And if marks are necessary,

marks should be allocated to self-declared development. In the CMP the final mark is determined by combining the assessment of essential and desirable LO's.

Reflective statements are particularly useful to capture students' perception of their own learning and development. In reflective statements students are asked to declare how they have applied their knowledge and understanding in a new situation; for example, in solving a problem. Reflective practices help students turn surface learning into deep learning. One of the challenges of assessing reflective statements is that it is very difficult to allocate a numeric mark to them. We could give marks for things we can count like the number of words, the number of grammatical mistakes or the number of times they start a sentence with 'I'; e.g. "I learned that…", "I believe…", "I noted that…", etc. Other than that, all sincere, well-written reflections have the same value as they mean something to the students who wrote them.

FINAL REFLECTIONS

In this paper the following ideas have been developed:

- CDIO-inspired activities are very good to teach students the knowledge, skills and competences required by industry in the 21st century.
- Students come to university to become the best possible professionals they can be.
- Constructive alignment and Bloom's taxonomy support the design of outcomes-based courses.
- Assessments very rarely capture the learning involved in the development of the students' identity as a professional.
- Quantitative assessments, i.e. evaluating student learning with numeric scales, are very blunt instruments to measure students' learning.
- Qualitative assessments provide more opportunities for students to demonstrate their learning, but they are more difficult to design, and their evaluation is subjective.
- A combination of quantitative and qualitative assessment instruments is recommended to capture students' competence and development process.
- Reflective statements are particularly good instruments to capture students' perception of their own learning and development.

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BIOGRAPHICAL INFORMATION

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SECURE LOCAL GENERATIVE AI CODING ASSISTANT: A CDIO APPROACH

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ABSTRACT

Generative Artificial Intelligence, referred to as GEN AI, is a buzzword that has gained immense popularity in recent years. The progress in generative AI has given rise to many applications in the domain of education. We have seen many of those models as coding assistants that enhance students' learning experience in introductory programming courses such as Python. In this paper, we present a new tool as a coding assistant that integrates the strengths of these models in computing education, showing how a CDIO approach can be employed to develop secure and effective AI-powered coding assistants that support novice learners while preserving academic integrity and ethics involved in such tools. This paper discusses the implementation of a containerized solution utilizing generative AI to provide accessible, secure, and efficient offline development tools. We have developed an AI code assistant that works offline, ensuring better privacy for students and learners based on the **qwen2.5-coder:0.5b** model and features a user-friendly Streamlit interface, all within a Docker container for offline execution to facilitate easy deployment and scalability and ensure security. This tool aligns with many CDIO standards to ensure a better educational experience both for learners and educators, which will be discussed in depth. Afterward, we will present the ethical implications of the implementation and then present the different components of the tool, to finally discuss in depth what can be improved for such solutions.

KEYWORDS

GENAI, CDIO, GENERATIVE AI, CODING ASSISTANT, STANDARDS: 2, 3, 5, 8, 11

INTRODUCTION

Ensuring secure tools for education remains one of the priorities in this era of AI. Natural language models have gained a lot of attention lately (the Chatgpt example Tan, 2023) not only for the usage rates worldwide, but also for how it switched the educational framework within the role of educators. Initially, irresponsible handling changed the way students deal with the information given, ignoring how those models can sometimes falsify answers, which is a wrong starting ground when learning a new subject. In addition, personal data are also collected, making educators responsible for structuring and defining how students can access that information.

In the era of artificial intelligence, we observe that many students lack technical depth and critical thinking aspects from the obsessive usage rate of AI tools such as generative AI. For this reason, it is crucial to develop innovative tools that both guide and challenge students, ensuring they remain actively involved as the ”human-in-the-loop” when utilizing AI.(Mollick and Mollick, 2023).

Researchers have suggested various approaches to address this issue, including the design of collaborative AI algorithms that leverage interpretable structures like knowledge graphs and decision trees (Agostinelli et al., 2021), but the simplest yet effective one is to implement AI agents that run locally and offline following ethics guidelines and providing students with a real-time learning experience. In this paper, we propose a CDIO framework-based tool that offers a structured way to construct a secure local AI coding assistant for students. This tool is capable to generate code, quizzes, and providing recommendations to students in a controlled environment, allowing them to maintain their agency and problem-solving skills (Agostinelli et al., 2021).

The CDIO framework **(CDIO Initiative, 2021)** is a well-established approach for both engineering education, which can be adapted to develop a secure local AI coding assistant. The key steps in our proposed Framework are:

• **Conceive**: by identifying the essential objectives and requirements for the secure local AI coding assistant, such as ensuring student activity, encouraging critical thinking, while preserving the ethical AI principles

• **Design**: by developing the architecture and core functionalities of the assistant, including the AI model, algorithms, knowledge representation, and the user interface.

• **Implement**: Creating the coding assistant as an extra learning tool and combining the designed components while respecting security measures.

• **Operate**: Deploy the assistant in the classroom setting, providing training and support to both students and teachers.

The paper is structured as follows, we start by outlining the CDIO standards with the coding assistant, by explaining the impact, the ethical implications and the relevance of the tool. Then we describe in detail the **HelloPy** coding assistant, the components, features and the study that was performed in an engineering school to assess students through the different expertise level while conforming with the syllabus of the python course. Then we display different examples of prompts and responses. Finally, we discuss and conclude the results of the study through students’ assessment.

ALIGNMENT OF AI CODING ASSISTANT DEVELOPMENT WITH CDIO STANDARDS:

Creating an AI coding assistant serves as an example for appropriate learning practices and an effective teaching tool, which are aligned with the CDIO framework. The necessity of defined learning outcomes that cover many skills described in Standard 2 aligns with the code assistant by creating adaptable activities that encourage disciplinary, interpersonal, and personal skills while boosting critical thinking, problem-solving, and cooperation

Moreover, the creation of the tool projects the interdisciplinary aspect which is highlighted in the third standard by integrating computer sciences, machine learning, deep learning and product building for an easy safe to use tool. On the other hand, the fifth standard is a projection of the life cycle of the creation of the coding assistant by following the cycle of **conceive-design-implement-operate** (CDIO) model. The educational challenges involved in this process come from real needs in education, such as reducing instructor's workload, generating engaging exercises or projecting real-world scenarios that are refined through the last phase of operating through performance metrics and feedback from students. Moving to Integrated learning experiences, which is standard number seven, is mirrored from the assistant as a tool that generates exercises that are adapted to any technical skill level without diverging from real-world scenarios. According to Standard 8, it supports active learning via interactive tasks that engage students.

Lastly, we have the eleventh Standard by the coding assistant's capability to generate real time feedback as the student starts engaging with many levels of exercises by providing corrected solutions that track the learning progress, which essentially helps foster continuous improvement in educational outcomes. **Table 1** displays the different standards associated with the coding assistant and its relevance.

Sustainable and ethical implications

The fast advancements in generative AI, such as large language models and diffusion models, have opened a broad range of applications in various domains, including education (Denny et al., 2023). However, using such AI-powered tools in educational settings raises many different ethical concerns, from plagiarism, to over-reliance on Artificial Intelligence, and the potential for biased or misleading outputs sometimes referred to as hallucinations (Kazemitabaar et al., 2023) (Denny et al., 2023. To address these concerns, ethically using AI must be one of the major considerations when designing and implementing those tools (Sharples, 2023). Furthermore, it is essential to design these tools to enhance the learning experience of students, while maintaining the fundamental principles of academic integrity.

The sustainable development concepts as part of the CDIO framework reflects a commitment to prepare students to this rapid evolution of technological adaptation of tools in their curriculum to have responsible engineering practices. By challenging them to consider the ethical implications in the problem-solving process, we ensure that not only are we training those students to be technically proficient but also to make them evaluate the impacts in the learning process by fostering a mindset of sustainable and ethical responsibilities. As industries and organizations globally adopt socially responsible practices, engineers with this knowledge will be better prepared to lead and contribute effectively.

Table 1. Relevance of the coding assistant within the CDIO standards

CDIO Standard	Description	Relevance to AI Coding Assistant
2	Covers personal, interpersonal, product, process, and service-building skills	The assistant creates exercises that are aligned with outcomes in programming, problem-solving, and critical thinking.
3	Including technical and non-technical skills in the learning activity	The assistant combines concepts from computer science, machine learning and educational principles.
5	Encourage students to conceive, design, implement, and operate systems by displaying the tool and explaining the concepts involved	Reducing instructor workload or creating adaptive programming exercises for students. Selecting appropriate algorithms, themes, and user interfaces to ensure effectiveness. Fine-tuning its outputs, ensuring they meet educational goals, and addressing any technical limitations, such as hallucination or bias. Continuous monitoring and refinement ensure that it remains effective and aligns with evolving educational needs
7	Encourage learning through real-world applications	The assistant offers exercises based on real-world scenarios, promoting applied learning and an interdisciplinary approach.
8	Promotes student engagement through interactive methods	Students engage in tasks generated by the assistant and receive immediate feedback to actively improve their skills.
11	Evaluates student learning through various assessments methods	The assistant monitors progress, delivers real-time feedback, and dynamically evaluates learners' needs.

In conclusion, this section highlights the importance of following relevant standards (**Table 1**) to ensure reliability, effectiveness and ethical responsibilities, making both actors (students and instructors) aware of the impact of their activities. Moreover, the standards conform to the coding assistant shows the establishment of a tool respecting data privacy, fairness and prioritization transparency, not only fulfill technical requirements but also contribute to develop trustworthy, accountable and socially responsible.

HELLOPY CODING ASSISTANT

Overview of the coding assistant

HelloPy is a coding assistant designed to support python learners through personalized experience and interactive support by using the Qween generative coding model (Qwen Team, 2024). The assistant walks through students from different levels to improve, and up-skill their

problem skills by being integrated in a user-friendly environment (Streamlit Inc., 2024) to make it a tool easily intractable with which run in real-time.

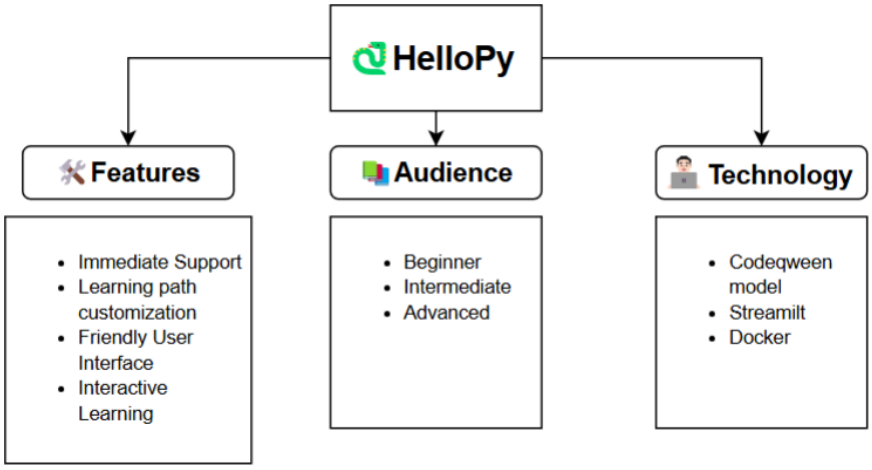


Figure 1. the HelloPy components

Study setting

In our approach, we experimented with the computer science department, in a Moroccan engineering school named **EMSI (École Marocaine des Sciences de l'Ingénieur École Marocaine des Sciences de l'Ingénieur, n.d.)**, where we gradually walk through students to reach an advanced level based on a set of predefined objectives, features, and assessment methods. All while ensuring that learners get adequate and personalized feedback and guidance from both the instructor and the coding assistant. The syllabus of the python programming language has strong foundational knowledge and progresses toward using the framework Django for web development to ensure a smooth transition from beginner to advanced equipping students with job-ready skills.

Level 1: Beginner

Objectives:
• Getting familiarized with the python syntax and basic programming exercises.
• Encouraging students to test different foundations to gain confidence through step-by step explanations and real-time feedback.
Features:
• Guided tutorials from both the instructor and the tool with easy-to-understand explanations.
• Real-time Error Handling.
• Suggesting code.
Assessments:
• Build-in-quizzes after completion of each lesson to test fully the comprehension of students
• Guided coding tutorial and initial challenges.

Level 2: Intermediate

Objectives:
• Develop problem-solving skills and an understanding of modular programming .
• Introduce intermediate concepts like file handling, error handling, and working with libraries (e.g., NumPy, pandas).

• Improve debugging and code optimization skills.
Features:
• Code debugging.
• Contextual explanation.
• Project-based learning.
• Code optimization suggestions.
• Library support.
Assessments:
• Completion of project based on milestones.
• Debugging code.
• Quizzes for intermediate concepts.

Level 3: Advanced

Objectives:
• Mastered advanced Python concepts such as object-oriented programming.
• Expose students to design patterns such as MVC (model-view controller) and MVT (model view template).
• Build projects based on web frameworks and APIs.
Features:
• Algorithmic challenges.
• Templates for real-world applications such as creating RESTful APIs with Flask or Django or training a machine learning model with scikit-learn.
• Performance metrics for the code.
Assessments:
• Completion of capstone projects, such as designing a REST API.
• Performing code tests with real-time feedback.
• Peer code reviews (simulated within the instructor).

RESULTS AND ANALYSIS

Evaluation of Student Learning Outcomes

The analysis was performed on students to assess and track the level of engagement, evaluating both the soft and hard skills aspects. As shown in both table 2 and figure 2, high scores in python coding proficiency (9/10) and assisted problem solving (8/10) is a true example of how including modern tools improve technical competencies.

For self-learning and adaptability with a score of (8/10) is a true example that supports the CDIO emphasis on extended learning and reflective practice. On the other hand, we have moderate to low scores, for debugging and optimization within the Django framework (7/10) and collaboration in projects (6/10) indicates a need to improve and develop extended tools that support collaboration and coordination.

To summarize, the results demonstrate the technical proficiency and direct learning that benefits both the students and instructors by exploring the full spectrum of the CDIO Framework.

Table 2. Evaluation of Student Learning Outcomes

Learning Outcome	**Score (0-10)**
Python Coding Proficiency – Writing clean, efficient Python code	9
AI-Assisted Problem Solving – Leveraging the generative offline coding assistant	8
Self-Learning & Adaptability – Learning without direct supervision	8
Debugging & Optimization – Identifying and fixing errors efficiently	7
Django Framework Understanding – Concepts, models, and views	7
Collaboration in Projects – Working in teams with Git, delegation, etc.	6

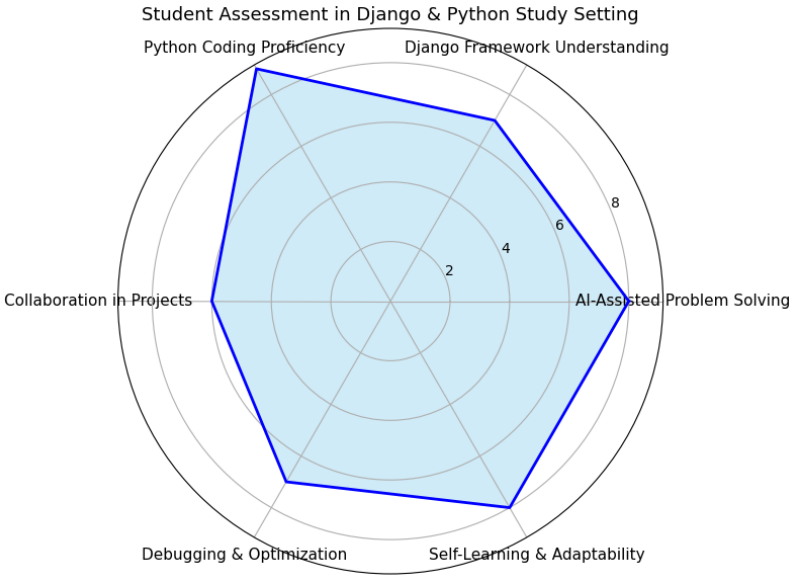


Figure 2. Study Setting for Django/Python with a Generative Offline Assistant

CONCLUSION

The result of the study shows the efficiency of using artificial intelligence, especially generative models to enhance the programming education spectrum across many skill levels. This efficiency is translated through a distinct set of prompts, adaptive learning tracks, and real-time feedback. It has also shown notable potential to engage students and boost their confidence by improving the learning process. The integration of the CDIO approach ensured a seamless transition from theory to real-world applications. Another key finding is that promoting local offline solutions while explaining to students how they can engage in responsible AI is a big step to ensure that the next students generation will develop a mindset that is not only framed in consuming tools but rather thinking if the tool is sustainable ,respecting the ethics of usage and protect their privacy. Furthermore, the solution is a win-win for both instructors and students since it reduces the workload of instructors and exposes students to a safe environment learning since AI is starting to impact teaching, learning and

thinking. To conclude, this paper is an extensive description of a generative AI coding assistant that conforms with the CDIO framework for the python programming language. The set of CDIO standards which applied to the assistant shows how we can leverage education optimally and safely for all the actors in that ecosystem and up-skilling classical teaching methods to merge with the continuous trends of technology with biasing some of the human aspects like critical thinking.

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BIOGRAPHICAL INFORMATION

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APPENDIX:

CODING ASSISTANT USER INTERFACE

The tool using the interface consists of three main components:

1. **The home interface**: that explains the role and scope of the assistant.
2. **Coding assistant**: where students ask the assistant about the different learning aspects of the python language (The list is still exhaustive)
1. **FAQs**: that explains the technology involved in HelloPy, from the generative model to the user interface and the docker container for the offline execution.

1.Home Interface:



Figure 3. First page when opening the code assistant.

2.Coding assistant:



Figure 4. Assistant

3.FAQs:

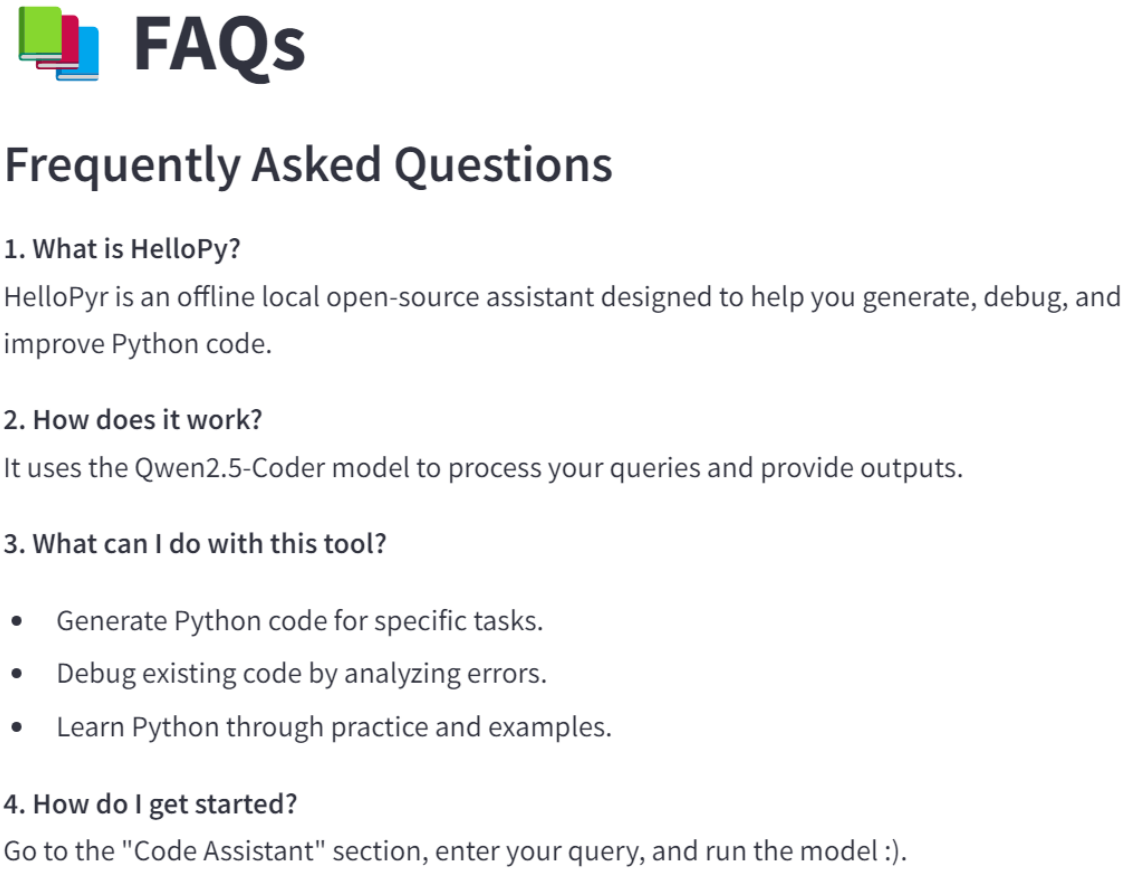


Figure 5. FAQs section

EXAMPLES OF PROMPTS WITH ANSWERS:

The different figures shown below is a small example of the capabilities of the model to generate adequate responses for all the students' level, detailed and well-structured to engage students and encourage them to surpass the difficulties such as communication and confidence.



Figure 6. Student first time asking the assistant

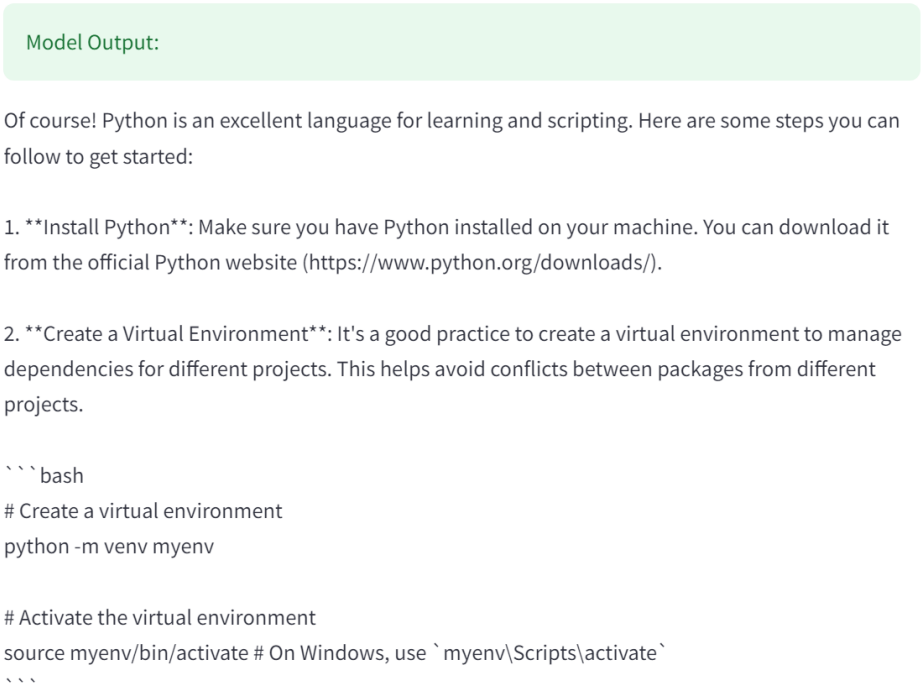


Figure 7. Output of first time asking the assistant



Figure 8. Beginner knowledge test

Model Output:

Of course! Python is a versatile programming language with a rich ecosystem for various applications. Here's a quick introduction to the basics of Python:

1. **Syntax**:
- Python uses indentation to define blocks of code.
- The `if`, `elif`, and `else` statements are used to control the flow of the program.
- Strings in Python can be single quotes, double quotes, or triple quotes.

2. **Data Types**:
- Numbers: Integers (`int`), floats (`float`), complex numbers (`complex`).
- Lists: Ordered collection of items that can contain elements of any data type.
- Dictionaries: Key-value pairs where keys are unique and values can be of any data type.

3. **Control Structures**:
- For loops: Used to iterate over a sequence (like lists, strings) or for processing data in a loop.
- Conditionals (`if`, `elif`, `else`).
- Functions: Define blocks of code that perform specific tasks and can be reused.

Figure 9. Output of the knowledge test



Figure 10. An advanced student request

Model Output:

Certainly! Here's a simple project idea that you might consider if you're looking for some guidance in Python:

1. **Flask Web Application**: This will serve as your web server and handle incoming requests, such as fetching data from a database or API.

2. **Database Interaction**: Use SQLAlchemy (or other database libraries) to interact with the database where your application needs to store and retrieve data.

3. **API Integration**: Use Flask-RESTful to create RESTful APIs for your application. You can define endpoints that allow users to perform CRUD operations on data.

4. **Data Storage**: Use Amazon S3 or Google Cloud Storage for storing your data locally, if you prefer.

Figure 11. Advanced output request

VERBAL PEER FEEDBACK IN PROJECT BASED LEARNING COURSE: INSIGHTS FROM MICROSOFT TEAMS MEETING RECAPS

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ABSTRACT

The integration of verbal peer feedback into engineering education supports the development of disciplinary literacy and essential professional skills, aligning with 'Standard 7: Integrated Learning Experiences' of the Conceive-Design-Implement-Operate (CDIO) 3.0 framework and reinforcing student agency in collaborative learning environments. This study examines the implementation of verbal peer feedback within a Project-Based Learning (PBL) engineering course and explores the affordances of Microsoft Teams Premium's Intelligent Recap feature to support instructors in monitoring, evaluating, and facilitating students' peer feedback interactions by capturing key discussion points, action items, and participation patterns during recorded feedback sessions. A two-step feedback process was employed, in which students provided written feedback on peer reports, followed by verbal discussions conducted and recorded via Microsoft Teams. These sessions were summarised using Microsoft's Intelligent Recap feature, helping to explicate peer interactions and facilitate instructor monitoring. The study revealed variability in the quality of student feedback, with some students offering in-depth critiques while others focused on surface-level issues, underscoring the need for more explicit guidance and training. While the Intelligent Recap tool proved useful in capturing key discussion points and streamlining review processes, it lacked the sensitivity to capture nuanced verbal interactions. Student reflections further indicated that participating in the peer feedback process improved their understanding of assessment criteria, boosted confidence, and promoted motivation. However, challenges remained, particularly in students' ability to synthesise information and provide well-articulated critiques.

KEYWORDS

Artificial Intelligence, Feedback Literacy, Project-Based Learning, Standards: 7.

INTRODUCTION

Feedback is the information provided to students, usually after they have completed a learning task or an assessment, about their understanding, performance, or behaviour. Feedback helps students improve and achieve their learning goals by highlighting strengths, identifying areas for improvement, addressing misconceptions, guiding skill refinement, and promoting reflection. Feedback also boosts motivation by demonstrating progress and encouraging growth, making it a vital tool for fostering mastery and educational success.

Henderson *et al.* (2019) posit that effective feedback must be constructive, delivered in a timely manner, and provide students with clear strategies for improvement (i.e. actionable). The work of Carless and Boud (2018) further showed that effective feedback is a dialogic, socially situated process requiring active learner engagement. Instead of passively receiving feedback, Carless and Boud (2018) recommended fostering students feedback literacy, that is, their ability to recognise the value and purpose of feedback (appreciating feedback), discern quality in one's own work and that of others (making judgement), the emotional responses that feedback can trigger (managing affect), and translate feedback into concrete steps for improvement (taking action) through teacher–student and peer interactions. Feedback practice should also extend beyond a single learning task, that is, students should be able to track their progress and continually integrate feedback into future, similar tasks ('feed forward'). Nicol (2020) showed that natural comparisons have a more pronounced impact on learning than formal feedback and argued for comparison to be the core mechanism of all feedback.

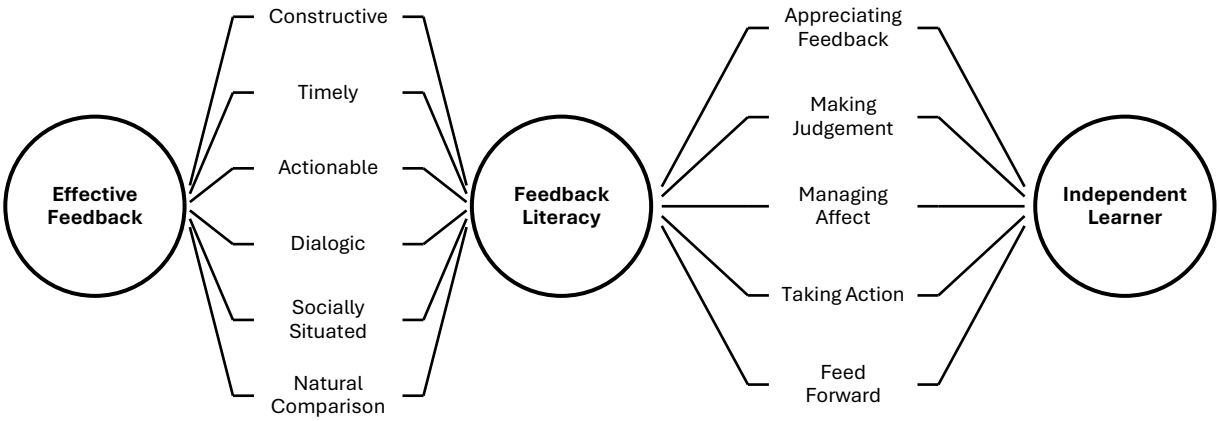


Figure 1. Schema showing how good feedback practice and feedback literacy are keys to developing the independent leaner

Despite its importance, providing effective feedback to students remains a significant challenge across many engineering disciplines, especially in courses taught using the Project-Based Learning (PBL) approach. Large class sizes and high student-to-instructor ratios hinder the provision of detailed, timely, and individualized feedback. Moreover, the diversity in students' learning needs and preferences, as well as the iterative and multifaceted nature of learning tasks and assessments in PBL courses, adds another layer of difficulty. To develop the disciplinary literacy and professional competencies needed to solve problems independently, feedback must be tailored and address both technical accuracy and broader professional skills that are often context-specific, further adding to instructors' workloads.

One approach that can address the challenge of providing feedback in PBL courses is the integration of verbal peer feedback with generative AI into the instructional design. Peer feedback involves students of similar status evaluating and providing constructive guidance on each other's work, rather than relying solely on instructors (Zheng *et al.*, 2024). Verbal peer feedback refers to feedback delivered in real-time or recorded conversations (Carberry *et al.*, 2016; Yoong *et al.*, 2023). Due to its dialogic nature, verbal peer feedback can enhance students' understanding of assessment criteria, promote critical professional competencies such as communication, collaboration, and self-regulation, and support the development of students' disciplinary literacy. As such, peer feedback in general, and verbal peer feedback specifically, aligns with 'Standard 7: Integrated Learning Experiences' of the Conceive-Design-Implement-Operate (CDIO) 3.0 framework. It supports the CDIO goal of preparing engineers who are technically proficient and effective in collaborative, real-world professional contexts.

Generative AI refers to artificial intelligence systems trained on large datasets to summarise or produce text, code, images, audio, or video outputs. These systems leverage advanced machine learning techniques to recognise patterns, interpret context, and evaluate digital content based on instructional prompts. Generative AI tools, such as Copilot and Intelligent Recap, are now integrated into Microsoft Teams Premium. These tools can summarise meetings by automatically capturing key discussion points, generating timestamps and action items, and enabling users to query the transcript. As such, Copilot and Intelligent Recap can support the design and incorporation of verbal peer feedback practices in PBL courses.

This projects in progress employed a qualitative case study design to investigate the affordances of Microsoft Teams Premium's Intelligent Recap feature in supporting instructors' monitoring of student verbal peer feedback practices. The specific aims and objectives are to:

1. Explicate students' verbal peer feedback practices; and
2. Evaluate the accuracy and pedagogical value of the meeting recaps in representing student verbal peer feedback interactions.

METHODS

DESN2000 Engineering Design and Professional Practice is a course offered across eight engineering schools at the University of New South Wales (UNSW) to a mixed cohort of students from Levels 2 to 4 of the program. The course is designed to develop students' engineering design capabilities, with a particular focus on the early stages of concept development in response to open-ended problems. It emphasises user-centred research techniques for understanding design challenges, alongside technical skills for concept generation, prototyping, and user testing to evaluate potential solutions. In addition, the course aims to strengthen key professional skills, including project management, teamwork, and communication.

In the 2024 offering of the course at UNSW's School of Chemical Engineering, 12 student teams, each comprising 6 members, were tasked with developing methods for valorising spent coffee grounds. The project spanned 10 weeks, and the students' solution had to meet two key criteria: (1) it must be feasible for the café to implement; and (2) it must generate a profit for the café. These requirements encouraged students to tailor their solutions to the café's operational context and business objectives, pushing them to think creatively and move beyond conventional options such as biofuel production or soil enhancement.

As part of the concept development stage, students were tasked with conducting a technology landscape survey, that is, a structured process for evaluating existing technologies, innovations, and research within a specific field. Students were required to produce a report identifying trends, gaps, opportunities, and cutting-edge solutions relevant to the valorisation of spent coffee grounds. In line with the course level (Level 2), only two technology landscape survey methods were taught to the students: (1) Literature review, where students used Web of Science, a citation database, to search for journal articles on technologies related to the use of spent coffee grounds, and (2) Bibliometric analysis, where students used Scite, an AI-powered tool, to summarise literature, extract key insights, and analyse citation contexts.

The students then formed pairs within their six-member teams to review and provide feedback on each other's technology landscape survey reports. This process was carried out in two steps: first, reviewers provided written feedback on content, writing style, and analysis; then, the reviewer and reviewee met on Microsoft Teams to discuss the feedback verbally. Meetings were recorded automatically, and detailed meeting summaries and attendance reports were generated by Microsoft Teams' Intelligent Recap feature once the meeting ended. Students were provided with a comprehensive guide outlining which aspects of the report to review and give feedback on. They were also instructed on how to provide feedback that is actionable.

Observational logs were maintained to document how students engaged with the verbal peer feedback activity. Students' written reflections on the peer feedback process were analysed thematically for recurring patterns, insights, and perceptions related to their engagement, learning outcomes, challenges encountered, and the perceived value of giving and receiving verbal peer feedback. A document analysis was conducted on one feedback session to evaluate the clarity, accuracy, and pedagogical value of the meeting recap, and the results were compared with human-coded transcripts to assess their reliability and usefulness. Ethical approval for this study was obtained from the University of New South Wales Human Research Ethics Committee prior to data collection (Project Reference Number: HC200047). All participants were informed of the study's purpose and their rights, including voluntary participation, confidentiality, and the option to withdraw at any time without consequence. Written informed consent was obtained from all participants, including permission for the recording and analysis of verbal peer feedback sessions conducted in Microsoft Teams.

RESULTS AND DISCUSSION

Features of Microsoft Teams Meeting Recaps

A typical Microsoft Teams AI meeting recap generated from the meeting transcript of an online peer review and feedback session is shown in Figure 2. The feedback sessions range from 30 min to 1 h per report. The 'Speakers' section visualises the duration and cadence of the students' interactions with each other (bottom left of the top screenshot). The 'Topics' section categorises the students' peer review session into distinct, colour-coded topics by duration (bottom left of the bottom screenshot). The 'Chapters' section (not shown) provides a time-stamped thematic breakdown of the peer review session, offering a structural overview of the discussion flow. The 'AI Notes' section includes two parts: 'Meeting notes,' summarise discussions and key decisions, and 'Follow-up tasks,' detail action items (right half of the top screenshot). Additionally, the recap offers a searchable transcript and meeting recording, enabling users to quickly locate topics using the search function, by clicking a topic in the 'Topics' section, or by using the 'Sync to video' feature (right half of the bottom screenshot).

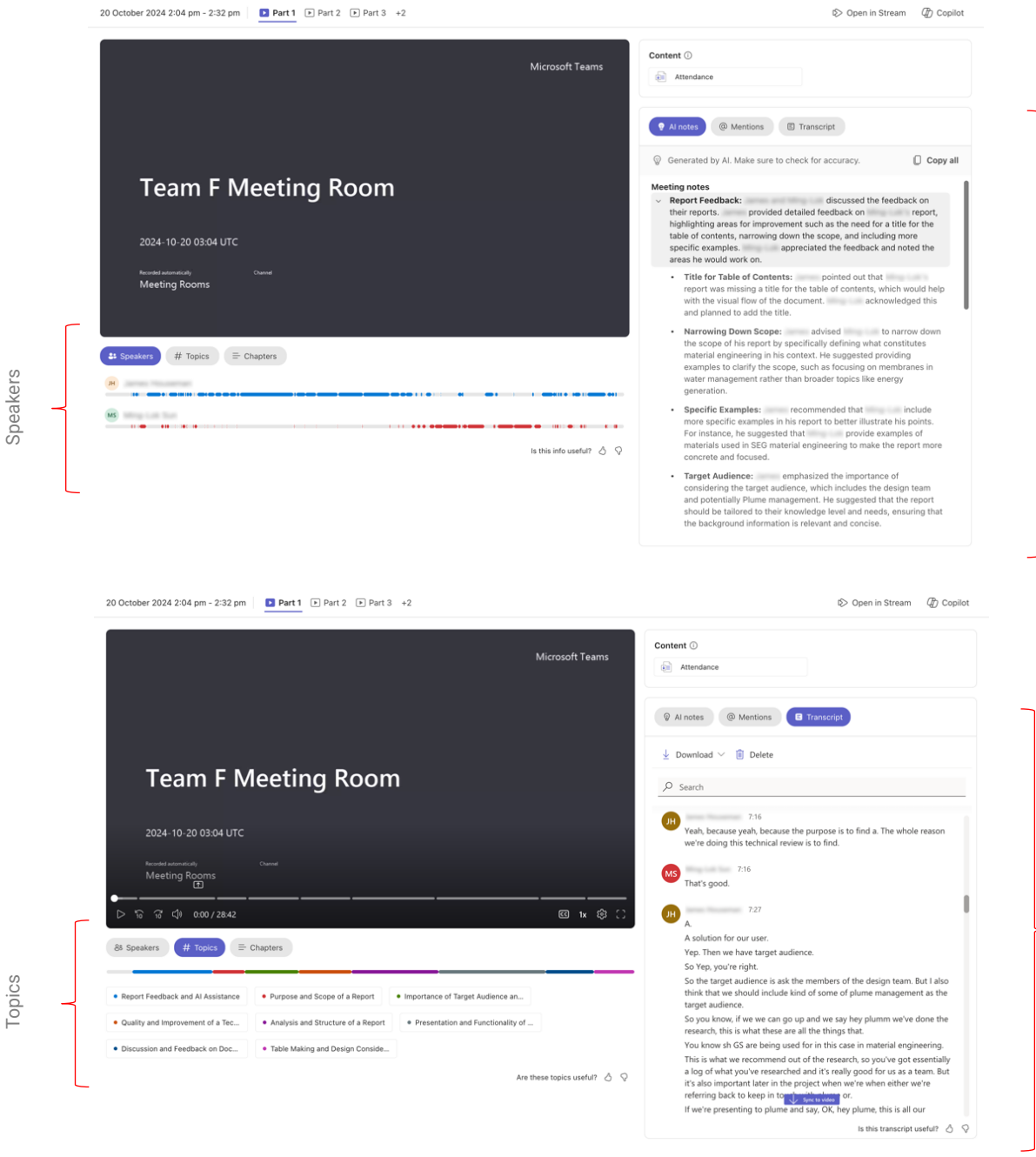


Figure 2. Screenshots of a Microsoft Teams meeting recap generated from the transcript of a recorded online verbal peer feedback session

Observation of Students' Verbal Peer Feedback Practices

Observation of students' verbal peer feedback practices revealed that they actively engaged in negotiation, sense-making, and peer support during the feedback process. For example, students discussing referencing would suggest the use of referencing tools for easier citation management and ensuring that all references are accurate and recent.

Most students closely followed the provided guide, often stepping through it carefully to ensure nothing was missed. The provision of a structured guide informed students about key areas of focus and assisted them in approaching peer feedback in a systematic and thorough manner. However, some students may have followed the guide too rigidly, limiting critical thinking and making their feedback formulaic, potentially missing unique or nuanced aspects of the work that fell outside the guide's scope.

The students demonstrated proficiency in providing feedback on the quality of communication and information within the reports. They were able to comment on the logical flow, clarity, and overall cohesiveness of the reports, and noted areas where these aspects were lacking. A few students also expressed confusion about the task requirements, including the use of track changes, document control, writing and formatting styles, referencing conventions, and the appropriate use of visual aids. Their uncertainty was heightened by differences in requirements compared to similar tasks in other courses they had taken.

Regarding the technical aspects of the report, students were generally able to provide feedback on the quality of information abstraction, particularly the clarity with which the underlying operating principles of the reviewed technologies were explained. Many students also emphasised the importance of using empirical data to support claims and accounting for statistical uncertainties, noting that these elements enhance the credibility and reliability of the report.

Where students struggled was in providing feedback on the quality of information synthesis within the reports. They found it difficult to provide feedback and justify how well the report used diverse sources, ideas, and data to form a logical argument for or against the selection of a specific technology. Many students also lacked the experience or language to critique whether the connections between concepts were clearly articulated or whether the evidence presented effectively supported the overall conclusions.

There is also a discernible variation in students' ability to provide verbal feedback across the cohort. While some students demonstrated strong skills in identifying key issues, offering actionable suggestions, and supporting collaborative improvement, others struggled to deliver meaningful or detailed critiques. For example, some feedback focused primarily on surface-level issues such as formatting or minor grammar errors, rather than addressing more substantive aspects like the clarity of ideas, strength of arguments, or alignment with project objectives. These challenges highlight the need for additional guidance and training in critically evaluating both technical and professional competencies in engineering contexts.

Clarity, Accuracy and Pedagogical Value of Microsoft Teams Meeting Recaps

Microsoft Teams' Intelligent Recap feature provides a streamlined way to summarise virtual meetings by capturing key discussion points, tagging speakers, and generating action items. In educational settings, particularly those involving peer feedback activities, this tool can be valuable for instructors seeking to review student interactions efficiently. It offers a time-saving solution for tracking participation, identifying discussion trends, and gaining a high-level overview of collaborative sessions. For busy educators managing large cohorts, the meeting recaps can act as a first-pass filter, highlighting potentially important moments in verbal peer feedback sessions without requiring them to listen to entire recordings.

Despite these strengths, document analysis showed the accuracy of meeting recap in capturing the details of verbal peer feedback remains limited. Peer feedback is inherently dialogic, often involving tentative suggestions, clarifying questions, and emotionally nuanced exchanges. These subtle yet critical aspects of student interactions are frequently oversimplified or excluded in the meeting recap. For instance, a student expressing uncertainty or offering constructive criticism with caution may be reduced to a vague or overly assertive summary, distorting the original intent. Furthermore, Intelligent Recap sometimes misattributes comments, especially in fast-paced discussions or when multiple speakers contribute simultaneously, which can undermine accurate assessments of individual participation or group dynamics.

Another limitation lies in the Intelligent Recap's handling of domain-specific language. In peer feedback sessions where students discuss technical topics, such as engineering principles, empirical data, or analytical methods, specialised terms or paraphrase can be interpreted inaccurately. This not only reduces the precision of the summary but also risks omitting or misrepresenting key learning moments. Additionally, the tool may struggle to recognise when students are synthesising ideas, negotiating meaning, or offering critical yet constructive commentary, all of which are essential components of high-quality feedback and collaborative learning.

Given these challenges, Intelligent Recap should be viewed as a supportive rather than standalone solution. Instructors should supplement the AI-generated meeting recaps with manual review of key dialogue segments, student self-assessments, and observational notes. This triangulated approach can help preserve the nuance and context often lost in automated summaries. Ultimately, while the Intelligent Recap feature contributes to administrative efficiency and surface-level monitoring, it currently lacks the fidelity required to capture the depth, complexity, and pedagogical value of verbal peer feedback in educational settings.

Student Reflection of the Verbal Peer Feedback

The students' reflections on their peer feedback experiences provide insights into their engagement with and perspectives on the verbal peer feedback process. Generally speaking, students found the peer feedback invaluable for improving their work, fostering collaboration, and enhancing their understanding of the subject matter.

Several students noted the benefits of participating in the peer feedback process as both givers (reviewers) and recipients (reviewees), particularly in relation to understanding and meeting the report requirements. They found the feedback they received valuable for identifying and clarifying issues in their own work, as well as for offering alternative perspectives on how to approach and improve their writing tasks.

> “The feedback on the report from my peer, J, was particularly helpful in identifying and clarifying issues within my work. Additionally, reviewing my peers' reports allowed me to identify common mistakes and areas where I could improve clarity in my own report, which ultimately helped strengthen my work.”

> “Report feedback from W was extremely useful as he made it clear that my analysis was missing certain sections, and through giving my feedback on his report, I was able to understand the marking criteria better.”

> “I was able to see my report from another perspective and more clearly recognise both key structural parts as well as how different report elements interact.”

Students expressed appreciation for the interactive, dialogic nature of verbal peer feedback, highlighting the importance of offering both encouragement and constructive input to their peers. Several students valued the opportunity to give feedback to peers at a lower academic level or receive feedback from those at a higher level. They viewed these interactions as a meaningful part of the learning experience and a key strength of the peer feedback process.

> “I did my best to mention good elements of her report and use constructive criticism where needed. When engaging with feedback, I accepted it without becoming defensive.”

> “When I provided feedback, I aimed to do it in a way that would still encourage A to keep enhancing the current work.”

> “I think I had a particularly important role here, as I am a 4th year student who has already finished all of 3rd year core. As such I have more experience with report writing and have lots of tips and tricks to offer to others. I believe [junior student] benefitted significantly from my feedback because of this.”

> “I did find the feedback meeting with [senior student] to be particularly helpful. I learnt a lot about some of the standard ways to write an engineering report.”

Students also noted that the peer feedback process increased their confidence and motivation. Two students further suggested that peer feedback should be incorporated into the other tasks their team was required to complete.

> “Talking with my teammates has given a lot of motivation in believing in myself.”

> “I think having greater opportunities to give feedback to other members of the group in various other tasks would have increased team cohesion and forced us to work more proactively.”

> “I think my peer review was one of the more productive meeting I had […] it’s easier for two like-minded people to agree rather than a group of 6 very different people, but I think this prepared me for what work in industry will be like. I feel a lack of team review at the end of each group assignment hinders the feedback my team members give, as I always found that anonymous feedback very productive for figuring out things I could personally improve on. There not being an anonymous avenue prevents a lot of actually honest feedback.”

CONCLUSION

Verbal peer feedback plays a vital role in fostering students' engagement, critical thinking, and professional development within project-based learning environments. By giving and receiving spoken feedback, students are exposed to diverse perspectives and interpretations, which not only enhances their technical understanding but also builds essential competencies such as communication, collaboration, and reflective practice. When integrated with AI tools like Microsoft Teams' Intelligent Recap, these feedback practices can be monitored and analysed more effectively, providing instructors with timely insights into student peer feedback practice. Although Microsoft Teams' Intelligent Recap is not without limitations, it offers valuable support in identifying areas where students may require additional guidance. This integration of peer feedback and AI can help alleviate instructor workload while ensuring students can receive timely and dialogic feedback. Ultimately, these combined approaches should support students' transition from novices to confident, literate professional in their chosen field.

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BIOGRAPHICAL INFORMATION

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CHALLENGE BASED LEARNING: CULTIVATING SOCIAL RESPONSIBILTY IN A COMMUNITY CONNECT COURSE

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ABSTRACT

The uplift of globalization and the implementation of cutting-edge technology have had a drastic effect on engineering education thus the demand for engineers who are not only good technically but also are conscious of the society and community is increasing day by day. The Community Connect course of SRM Institute of Science and Technology is conceptualized under the Challenge Based Learning (CBL) framework to prepare students for social responsibility, ethics, and collaborative problem-solving in the engineering sector. Students are involved in real-world community challenges that encourage technical competence with empathy through interdisciplinary teamwork. Implemented with the ADDIE model, the course was designed as follows: analysis, design, development, implementation, and evaluation phases, and aligned to CDIO standards 2, 5, 7, and 11. In 2024, 600 students from Computer Science, Electronics and Communication, Electrical and Electronics, and Mechanical Engineering disciplines successfully completed 115 community engagement projects that address societal challenges aligned with Sustainable Development Goals (SDGs). The projects were a combination of the development of students' CDIO skills, and the accentuation of the ethics in the practice and service of the engineering. The assessments revealed a considerable step forward in their higher-order thinking skills, teamwork, and practical problem-solving. This paper documents the course design and outcomes toward a model for embedding social responsibility into engineering curricula to meet the changing demands of society.

KEYWORDS

Challenge Based Learning, ADDIE Model, Understanding by Design, Community Engagement, Standards: 2, 5, 7, and 11.

INTRODUCTION

Rapid technological progress and globalization demands that future engineering graduates be technically competent and socially conscious and capable of solving complex societal problems (National Academy of Engineering 2004). Engineering education which has been traditionally meant for building technical competence is being emphasized to include social responsibility and community engagement as part of its curriculum (Sheppard et al., 2009). This development in engineering education, reflects the realization that engineers are probably one of the most impactful groups of people in society and they will have to learn how to cope with ethics, environment, social dimensions on their work. Under this need, with the help of pedagogical frameworks such as Challenge-Based Learning (CBL) is becoming increasingly popular among existing models that stimulate critical thinking, interactivity and civic sense among future engineers (Johnson et al., 2011).

According to Nichols et al., 2020, CBL is a learner-centered approach that captivate students to solve real-world problems with the help of diversified stakeholders working collaboratively. Based on experiential learning theory, CBL is structured to promote active learning, multidisciplinary teamwork and reflection which is perfect for solving contemporary communities' problems (Kolb 1984). This community-centered projects with the keen involvement of students in CBL, provide opportunity to develop technical skills along with empathy, communication and understanding of societal needs (Barrett 2017).

The Community Connect course, designed for third year undergraduate engineering students adopts the CBL framework to establish social responsibility & inclusive community engagement. This is a course that is organized around projects that are collaborative, as the students work with local communities/non-profits and community members to identify and solve problems. This paper studies implementation of CBL in Community Connect course and the social responsibility element that it imparts to undergraduate engineering students. More specifically, the study explore how engagement with real-world problems helps students develop Conceive, Design, Implement, Operate (CDIO) skills to address community needs and reflect on their responsibilities as community-minded engineers.

This study contributes to the literature within engineering education on experiential learning, and provides evidence on how CBL can be sensibly embedded in the curriculum to incident with the vision underpinning education for sustainable development (UNESCO, 2017). The Community Connect course serves as a model of rethinking engineering education through experiential learning that is embedded in social responsibility, a hands-on approach tied to the evolving needs of society. The ADDIE model, a systematic instructional design framework was used to Analyse, Design, Develop, Implement and Evaluate this community connect course (Tu, Zhang, & Zhang, 2021). This methodology makes certain that the course aligns with its goal of developing social responsibility and community engagement focus for undergraduate engineering students. This work addresses CDIO standards 2, 5, 7, and 11 on Learning Outcomes, Design-Implement Experiences, Integrated Learning Experiences, and Learning Assessments. The research methodology employed to effectively implement CBL through a Community Connect Course uses a mixed-method approach, combining qualitative and quantitative research. To assess the effectiveness of the CBL implementation, quantitative research focuses on assessments of students' skills and knowledge gained during the course, while qualitative research examines reflective journals in the form of student reports, followed by oral examinations.

ANALYSIS PHASE: INSIGHTS OF GLOBAL CONTEXT, CHALLENGES AND OPPORTUNITIES

The Analysis Phase then sets the ground for the design of the Community Connect course through in-depth examination of global trends, systemic challenges and new opportunities arising from them. It is this step that involves making sure the course is useful, relevant and addresses both immediate students' needs as well as larger societal goals.

Global Context

Higher education institutions play a significant role in moulding the values, skills, and attitudes of future engineers. As the world faces systemic challenges such as natural disasters, climate change, community related issues and social inequality, there is a huge need on cultivating social responsibility and community engagement within academic curricula. The worldwide transition indicates an expanding commitment that education must go beyond disciplinary silos in order to engage the complex societal challenges and enable students to play a role in their communities — first locally, then beyond.

Across the world, higher education institutions have taken initiatives to foster social responsibility. In the United States, service-learning models are integrated with academic instruction, to impart social responsibility and reflective thinking (Bringle & Hatcher, 1996). The universities in Europe have adopted the model "third mission," which emphasizes on societal engagement integrated with teaching and research (E3M Project, 2012). National Education Policy (2020) and the University Grants Commission (UGC) of India also highlight the need of community engagement in higher education as one of the key components (Government of India, Ministry of Education, 2020). Acknowledging education as a socialisation process towards socially responsible citizens, these frameworks recommend that community-based learning should be integrated into curricula to enable the students for solving societal issues and being a part of national progress (University Grants Commission, 2019) . In Australia, universities work with communities to develop solutions to local community problems (Smith et al., 2020). These programs are designed to create culture of engagement beyond the confines of institutional framework.

Challenges

Firm Academic Programs: Engineering programs often emphasize program specific technical knowledge and skills, providing less importance to interdisciplinary/multidisciplinary courses or service-based learning. The rigid focus on technical aspects is very challenging to adopt community engagement without compromising core engineering concepts (Sheppard et al., 2009).

Dearth of Institutional Backing: Successful community engagement initiatives need resources, administrative support and faculty development. Watson et al. (2011) assert that institutions without policies or funding for such programs struggle to maintain them.

Limited Knowledge of Faculty: Most of the engineering faculty has no experience of teaching about responsibility or community-based projects. This skills gap makes it difficult to effectively execute upon engagement activities.

Views and Motivation of Students: Engineering students tend to see technical competencies over community and ethical engagement as the latter is often considered an irrelevant side-

train to their professional goals according to Bielefeldt, Paterson & Swan (2010). Changing this mindset is hard work.

Complexity of Assessment: Measuring if community engagement truly benefits students and the communities involved is hard. There are few standardized metrics to measure the intangible outcomes of empathy, civic responsibility and ethical awareness (Bringle & Hatcher 1996).

Obstacles in Logistics: Community engagement project organizing means coordinating with external stakeholder, travel management and safety and academic calendar of the institution with project lifecycle. But logistical obstacles can discourage participation.

Opportunities

Adopt Challenge-Based Learning (CBL): In engineering education, CBL provides an efficient mode for the integration and practice of community engagement. Engaging with 'real world problems' allows students to combine technical skills, with empathy and ethical reasoning (Johnson, Smith et al. 2011).

Collaborate with Industry and Non-Governmental Organizations (NGOs): Collaborating with industry and NGOs will be the backbone for community projects to have resources, expertise and the real-world relevance. These alliances enrich the depth and effectiveness of engagement initiatives (Rao & Chandran, 2020).

Use of Technology: Digital platforms and tools give students the ability to work on community ventures virtually, which increased the opportunities for engagement across great distances and logistical obstacles (Ribeiro et al., 2018).

SDGs and International Frameworks: The United Nations Sustainable Development Goals (SDGs) offer a globally recognized framework for community engagement initiatives. Projects aligned to SDGs increases visibility and the wider meaning could be seen globally (UNESCO 2017).

Interdisciplinary Partnerships: Interdisciplinary partnerships are often necessary for social responsibility efforts. Engineering students should develop as holistic problem solvers and work with peers in the medical sciences, allied health sciences, social sciences, arts and business encourages a wider range of perspectives (Smith et al. 2020).

Improved Employability Capabilities: Community projects that involve students developing critical skills (teamwork, communication and ethical decision making) are recognized as popular with employers. This can serve to empower students and induce motivation.

Social Effects and Reputation: Community Engagement initiatives that work impact society and the reputation of the institution. This double benefit inspires institutional commitment to such programs.

DESIGN PHASE: BACKWARD DESIGN APPROACH

The Understanding-by-Design (UbD) framework, a backward design approach is adopted for the Community Connect course to ensure constructive alignment between course learning outcomes, assessment strategies and instructional activities. This structured framework enhances the scope of the course to cultivate social responsibility, community engagement,

and CDIO skills among the engineering students. The following sections describes how the Community Connect course suits in to the UbD framework.

Stage 1 – Desired Results

The first stage of Understanding by Design (UbD) Framework will look into formulate the big take away or what we want our students to understand in Community Connect course designed. This stage establishes the bedrock for student learning by defining what students should know, understand, and be able do through their learning. Table 1. elaborates the first stage of the UbD process.

Table 1. First Stage – Desired Results

KEY GOALS AND OBJECTIVES • Instil social responsibility and values of ethics among students • Provide students the ability to conceive and act on real-world societal issues • Cultivate professional communication, teamwork, and technical competencies through community engagement • Encourage the students to relate theory with practical work-based application and experience
UNDERSTANDINGS *Students will understand* • the importance of engineering in addressing societal challenges • the meaning of community engagement as a step in sustainable development • the moral implications of their professional obligations
ESSENTIAL QUESTIONS *Students will keep considering* • How can engineering knowledge be applied in addressing challenges of community? • What is the place of empathy and ethics in dealing with society problems? • How do inclusive partnerships result in the delivery of sustainable solutions?
LEARNING OUTCOMES • Apply social knowledge in the real world of work and get attached to the community • Demonstrate competency in societal problems and finding solutions • Effectively implement skills in professional communication, technical writing and using multimedia tools • Develop ability to work as an individual and in a group as an effective team member • Master the professional and ethical responsibilities of a social worker

Stage 2 – Assessment Evidence

In the second stage of Understanding by Design (UbD) framework, we design assessment tools that access students' understanding, skills and knowledge. This stage guarantees that the evaluation techniques are linked with results that needed as desired in Stage 1. Through developing clear and valuable assessments, educators are able to verify that students have

attained the learning outcomes successfully. Table 2. elaborates the second stage of the UbD process.

Table 2. Second Stage – Assessment Evidence

PERFORMANCE TASKS *Students will* • Identify a community problem which may be related to any one of the following: Access and Abilities, Education and Outreach, Environment, and Human Services. • Collaborate with NGOs and Non-Profit Organizations (NPOs) working on the community problem identified. • Study the community problem with the support of the NGO/NPO • Conceive, design and develop an engineering solution for the community problem identified. • Prepare a detailed report comprising problem identification, conceptual design, project specifications and budget for the proposed community project. • Phase I assessment will include a presentation of the problem statement and proposed solution followed by oral examination evaluated by a committee. • Implement the project with the detailed design process. • Deliver and operate the project to the community and evaluate whether the project is sustainable. • Phase II assessment will include a presentation of the detailed project work followed by oral examination evaluated by a committee.
CRITERIA FOR ASSESSMENT Phase I • Engineering Design Process (20%) • Level of innovation in the project (15%) • Project alignment with the community problem (20%) • Oral examination (5%) Phase II • Deployment of the project in the community and check for sustainability (15%) • Project and financial management (10%) • Project report and presentation (10%) • Oral examination (5%)
OTHER EVIDENCE • Reflective journals of personal learning, transformation and growth • Feedback from community partners or NGOs or NPOs. • Peer feedback in terms of teamwork and collaboration

Stage 3 – Learning Plan

Understanding by Design (UbD) Stage 3 is a creation of instruction pathway to guide and support the learners in both stage 1 achieving the desired results and stage 2 doing well on assessments. Learning plan for Community Connect course ensure students are engaged in the learning and incrementally building their understanding so they attain the learning objectives through authentic/practical experiences. Table 3. elaborates the third stage of the UbD process.

Table 3. Third Stage – Learning Plan

PREPARATION PHASE:

Instructional sessions on

- Introduction to societal or community challenges, societal responsibilities, engineering ethical practices, sustainable development goals (SDGs), and the role of engineering in community development.
- Professional communication and teamwork.
- Categories of community problems, identification and analysing the problem.
- Identification of NGOs/NPOs and collaborating with them.
- Digital tools for project documentation and presentation.

COMMUNITY ENGAGEMENT PHASE:

Problem Identification and Partnership (Phase I):

- Students work individually or in groups with an NGO/NPO to figure out a community problem to solve.
- Data related to the problem is collected by conducting field visits and stakeholder interviews.

Conceive and Design (Phase I):

- Students conceive ideas for the problem identified.
- Design process with project specifications and budget are created under the supervision of the faculty mentor

Implement and Operate (Phase II):

- Students implement the project design in the institute and involve the community periodically for testing and feedback under the support of NGO/NPO.
- During operate phase, students ensure the sustainability and scalability of the proposed solution.

REPORTING AND ASSESSMENT PHASE:

Project Report Preparation:

- Students write a report of the whole project (problem analysis, project design, implementation and community engagement)
- Geotagged photos and multimedia evidence are substantiated for the demonstration of engagement.

Assessments:

- *Phase I Assessment:* Students present problem identification, NGO/NPO partnered, conceived engineering solution, design process, budget and timeline of the community engagement project.
- *Phase II Assessment:* Students deliver a final presentation elaborating the detailed project implementation and outcomes. The presentation is followed by oral examination conducted by an evaluation committee.

DEVELOPMENT PHASE

In the development phase, all resources and objects required for Community Connect course are developed for effective delivery. Key components of this include designing detailed instructional modules on societal challenges, sustainable development goals, and ethical practices. These modules also present guidelines for conducting fieldwork as well as participating with NGOs/NPOs along with technical writing tutorials and instruction on multimedia use in report writing. Templates of projects are established for problem identification, project specifications, budget proposals, reflective journals, and geotagged photo documentation. Complete evaluation rubrics have been developed that include assessment performance tasks, reports of projects, presentations, oral examinations, reflective journals, and peer feedbacks.

Online video conferencing with NGOs or NPOs is employed to tackle the logistics barrier challenge. Institute Learning Management System (LMS) is used to share the instructional materials and reports and track the progress of the project. Training and development of the faculty is conducted before the commencement of the course to prepare instructors to mentor students on community engagement, assesses intangible outcomes like empathy, and manages interdisciplinary collaborations (Rajeev & Vairavel, 2023). Also, step-by-step guidelines relating to course facilitation, assessment, and feedback mechanisms are provided in the faculty manuals.

Memorandums of Understanding (MoUs) are exchanged between the institute and NGOs/NPOs who are working on the local community issues. This MoUs help the students to collaborate effectively with stakeholders. A project selection framework is put in place to align chosen community problems with SDGs, ensuring meaningful and impactful engagements. Pilot projects are conducted before full-scale implementation to test course components, gather feedback, and refine processes. Inputs are gathered from students, faculty, and other stakeholders for clarity, usability, and relevance. In the end, all materials are finalized for delivery, including a course handbook that outlines program objectives, timelines, activities, and assessments, as well as a Community Connect Toolkit with hands-on tools and resources for students while they conduct their fieldwork and implement their projects.

IMPLEMENTATION AND EVALUATION PHASE

The Community Connect course was offered to undergraduate engineering students during their study in semester 4 and 5. A batch of 600 students, spread out over four disciplines, namely Computer Science and Engineering (CSE) with 240 students, 120 students in each of Electronics and Communication Engineering (ECE), Electrical and Electronics Engineering (EEE), and Mechanical Engineering (ME) have undergone this course in the year 2024.

During their study in semester 4, instructional sessions of duration 15 hours were conducted to impart societal or community challenges, societal responsibilities, engineering ethical practices, sustainable development goals (SDGs), and the role of engineering in community development, professional communication and teamwork, categories of community problems, identification and analyzing the problem, identification of NGOs/NPOs and collaborating with them, digital tools for project documentation and presentation. After the preparation phase, students were grouped into teams of 4–5 members, comprising members from CSE, ECE, EEE, and ME ensuring interdisciplinary participation and obtain diverse perspectives for the community problem identified. During summer vacation, student teams had partnered with NGOs/NPOs to figure out a community problem to solve and collected data related to the

problem by conducting field visits and stakeholder interviews. At the start of the semester 5, student teams were assessed with their submitted report on problem identification and proposed engineering solution by the evaluation committee. After phase I of assessment, the teams have started progressing towards the design, implement and operate parts of the project which were carried out in the institute project space. The similar exercise was given as an experience during their first year of study in the course Philosophy of Engineering but with less complexity (Vairavel & Rajeev, 2024) During the project work, the teams were instructed to collaborate with the community in the weekends for testing and evaluation and get constructive feedback for necessary improvements. After successful implementation and delivery of the project to the community, the students' knowledge and skills acquired during community engagement were assessed at the end of the semester 5 using assessment rubrics.

Totally 115 community engagement projects were successfully completed by the students in the year 2024 as a part of Community Connect Course. Out of 115 projects, 66 are based on access and abilities, 9 based on education and outreach, 21 based on environment and 19 based on human services. The projects have addressed SDGs such as SDG 3 – Good Health and Well Being, SDG 4 – Quality Education, SDG 6 – Clean Water and Sanitation, SDG 7 – Affordable and Clean Energy, SDG 14 – Life Below Water, SDG 16 – Life on Land and SDG 17 – Partnership for the Goals. The summary of the community engagement projects and feedback given by the students about the course is shown in Figure 1. The analysis shows that about 75 percent of the students could conceive ideas for the societal problems through handholding and only 17 percent could solve independently without guidance. Above 70 percent have given excellent for assessment and evaluation methods used which will be improved in the year 2025. The students have expressed that this kind of real-world problem solving through community engagement makes them to feel as an engineer during their period of study. The course has significantly enhanced their knowledge on social responsibilities, professional communication, problem solving, critical thinking and CDIO skill.

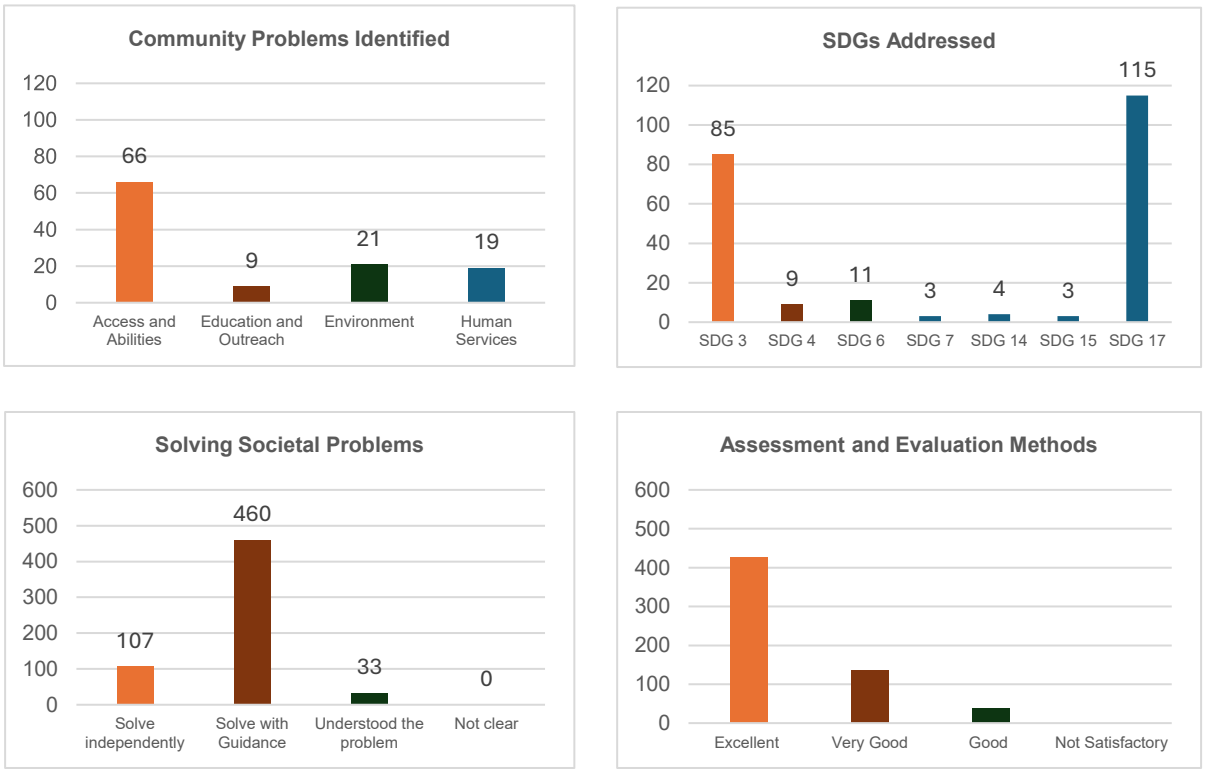


Figure 1. Community Engagement and Feedback Analysis

Impact

The application of Challenge-Based Learning (CBL) via the Community Connect Course has had a considerable positive influence on students as well as the community. NGOs have increasingly accessed the course, posing more varied real-world problems, resulting in signing more Memorandums of Understanding (MoUs). Through such collaboration, students have become better connected with the community as they work on actual challenges relevant to the needs of the community.

Consequently, the community has contributed more intricate problems, which not only improved students' problem-solving skills but also generated innovative ideas. The ability to solve real-world problems has allowed students to think critically and come up with creative solutions that can potentially benefit the community.

The CBL methodology has also allowed for increased interaction between students from different years. Increased numbers of juniors have begun interacting with seniors, developing a peer mentoring culture. This sharing of information and experiences has helped develop social competencies, whereby students learn essential skills in teamwork, communication, and leadership.

Furthermore, the students have developed considerable personal and professional development in their portfolios. The experience in community-based projects has increased their sense of social responsibility and enhanced their ability to solve problems associated with society. Generally, the application of CBL has not only helped the students in academic terms but has also instilled a stronger community attachment, shaping well-rounded students equipped to deal with actual challenges.

Limitations

Following are some limitations experienced during the implementation of Challenge-Based Learning (CBL) through the Community Connect Course:

Limited Range of Community Issues: While NGOs are reporting more problems, the extent of challenges covered are constrained by the scope or emphasis of the organizations, which did not address all issues of concern in the community.

Time Limitations: Tackling community issues had demanded extensive time allocation. Students slightly found it difficult to coordinate these projects with their studies.

Uncertainty in Measuring Long-Term Effect: The long-term effect of the solutions devised by the students is still hard to measure, and need extended intervention longer than the course period.

Implementation Barriers: Even when students developed excellent ideas, the implementation of solutions in the community was constrained by administrative, legal, and logistical issues, requiring several processes for effective execution.

CONCLUSION

The Community Connect course is a model of best practices for embedding social responsibility and community engagement in engineering education. Integrating the challenge-based learning approach and CDIO guidelines, the course connects technical

competence with civic responsibility. The ADDIE model based systematic implementation ensured that the course achieved all its objectives for an ethical awareness as well as teamwork and critical problem-solving among the students.

In 2024, the 115 projects that were completed by 600 students covered a wide range of social challenges and thus were through positive impact on the communities while they were in alignment with the several sustainable development goals. Through a holistic approach and collaboration with NGO and NPO professionals, students took the role of community developers that were concerned with the long-term impact and the environmental wellbeing. Results of assessment showed tremendous improvement in students' social awareness, technical skills, and professional communication skills. "Community Connect" is a course that explicitly imparts the skills of knowledge application and ethical conduct within a broader understanding about changing engineering education.

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ENGINEERING EDUCATION RESEARCH

DESIGNING A DIGITAL TWIN VIRTUAL LAB FOR PLC APPLICATIONS

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ABSTRACT

This study evaluates the integration of a Digital Twin (DT) virtual model into the *ET0917 Programmable Logic Controller (PLC) Applications* module, assessing its impact on enhancing learning by simulating car park scenarios beyond the constraints of the physical lab. Aligned with CDIO principles, all labs in ET0917 are designed to bridge theory and practice, equipping students with essential skills in ladder logic programming, I/O device configuration, and automated control system development. The DT virtual lab extends these learning opportunities by providing a dynamic, interactive environment that overcomes the limitations of the standard lab setup. The DT virtual lab was designed incorporating the principles of Self-Determination Theory and Cognitive Load Theory to strategically reduce extraneous cognitive load while deepening student engagement. Survey and interview feedback from students and staff indicated positive responses, with students reporting improved visualization and a stronger grasp of problem-solving concepts. Building on this success, future developments will expand DT technology to incorporate additional scenarios beyond the standard lab setup. This will broaden the scope of learning and application, particularly by simulating future scenarios that are not physically possible. This approach aims to nurture students' futures thinking competency, preparing them to anticipate and address emerging engineering challenges while strengthening their ability to conceive, design, implement, and operate solutions within the CDIO framework.

KEYWORDS

Digital Twins, Visualization, Self-determination Theory, Extraneous cognitive load, CDIO Syllabus, CDIO Standards 1, 6, 7 and 8.

NOTE: Singapore Polytechnic uses the word 'courses' to describe its education 'programs'. A 'course' in the Diploma in Chemical Engineering consists of many subjects that are termed 'modules'; which in the universities' contexts are often called 'courses'. A teaching academic is known as a 'lecturer', which is often referred to a as 'faculty' in the universities.

DESIGNING EFFECTIVE MULTIMEDIA LEARNING: A BLEND OF MOTIVATION AND COGNITIVE LOAD PRINCIPLES

The accelerated digitalization in the manufacturing sector has necessitated updates to our engineering curricula to prepare students for Industry 4.0 and Smart Manufacturing. Among the emerging technologies, Digital Twin (DT) has gained significant importance. DT technology is a virtual representation of physical objects, systems, or processes. With its capability to mimics the characteristics, behaviors, and functionalities of its real-world counterpart, it offers solutions for creating learning tasks that are not feasible in physical labs.

However, research shows that adopting technology alone does not inherently improve learning outcomes. For example, Madden *et al.* (2019) found no significant differences in learning outcomes after comparing different teaching methods including hands-on activities, virtual reality, and desktop simulations. Similarly, a meta-analysis conducted by Karich *et al.* (2014) concluded that learner control in multimedia environments had negligible overall effects on outcomes. To enhance learning outcomes, Rey *et al.* (2019) suggested presenting the multimedia instruction in meaningful, progressive stages that support human cognitive processes. Progressive and meaningful implementation of DT technology can resolve these issues by providing structured, interactive, and realistic simulated environments that enhance learning and motivation. DT technology offers immediate feedback mechanisms, which build competence by providing clarity and reinforcing progress (Hattie & Timperley, 2007). Additionally, the interactive features of the DT model promote autonomy by enabling students to choose their problem-solving methods, while carefully managing cognitive load to avoid overload (de Brabander & Martens, 2014).

This paper explores the use of DT for students from the School of Electrical and Electronics Engineering (SEEE) in Singapore Polytechnic (SP). The goals are twofold: firstly, to leverage the advantages of DT to simulate scenarios not feasible to create in physical labs; and secondly, to help students appreciate the impact of digitalization in the manufacturing industry. This initiative aligns with Standard 6, which recently added digital workplaces into education, and CDIO Syllabus (2.4.5) Staying Current on the World of Engineering. To achieve these goals and address the challenges, we draw on Self-Determination Theory (SDT) and Cognitive Load Theory (CLT) to offer guiding principles for achieving this balance. As proposed by Ryan and Deci (2000), SDT identifies three innate psychological needs namely autonomy (control over one's actions), competence (feeling capable and effective), and relatedness (feeling connected to others) which are essential for fostering intrinsic motivation, deeper engagement, and active participation. At the same time, CLT, introduced by Sweller (1998), highlights the importance of managing cognitive demands by minimizing extraneous load.

OVERVIEW OF THE MODULE: ET0917 PLC APPLICATIONS

In the SEEE, all second-year students from the Diploma of Electrical and Electronics (DEEE) are required to take the module *ET0917: Programmable Logic Controller (PLC) Applications.* This module is designed to provide hands-on, experiential learning that connects theory with practice in the context of manufacturing and process automation. It adopts an active and integrated learning approach, in line with Standards 7 and 8, to foster meaningful engagement and practical application. The module spans 15 weeks, with 5 hours per week, including 3 hours in a laboratory setting. The lab activities are centered around authentic, real-world tasks (Standard 1) and are sequenced progressively from simple practical exercises to more complex industry challenges. This progression enables students to appreciate and reflect on

the *Roles and Responsibilities of Engineers (4.1.1)* and the importance of *Training and Operations (4.6.2).*

Through this module, students gain proficiency in essential PLC skills, including ladder logic programming, configuring INPUT/OUTPUT (I/O) devices, integrating human-machine interfaces, and developing automated control systems. These skills are fundamental for designing, programming, and maintaining industrial automation systems used in manufacturing and process industries. In the lab, students engage in hands-on learning activities such as developing ladder logic programs, configuring hardware, and troubleshooting systems. These activities foster *systems thinking (2.3)* as students analyze the relationships, interactions, and interfaces among I/O devices. The module also emphasizes *Experimentation, Investigation, and Knowledge Discovery (2.2)*, encouraging students to engage in *self-awareness, self-reflection, and metacognition (2.4.6)* as they assess their skills, strengths, and areas for improvement.

Additionally, the module develops *interpersonal skills (3.0)*, *adaptability and flexibility (2.4.3)*, and CDIO skills, which include systems thinking, implementation, and integrated problem-solving competencies *(4.3) – (4.6).* These competencies are further enhanced through structured practical exercises (Standard 7) and a capstone CDIO project (Standard 5). This integration of attitudes and technical skills ensures a holistic learning experience, equipping students for the complexities of both the industry and society.

DESIGNING THE LEARNING TASK INCORPORATED WITH DT TECHNOLOGY

Incorporating DT technology into learning tasks requires a timely and structured approach to prevent increasing cognitive load that hinders learning. Table 1 outlines the PLC module's three-week schedule, which helps illustrate the rationale for introducing the DT lab in Week 3.

Week 1: Students are introduced to the fundamental concepts of PLC programming, basic functions, and applications during lectures. In the lab, they familiarize themselves with the hardware layout, identify parts and their functions, install PLC software tools, and get accustomed to the programming environment.

Week 2: Students learn about basic I/O devices and develop simple ladder logic programs during lectures. In the lab, they apply this knowledge through mini learning tasks, gaining hands-on practice in constructing ladder logic programs and working with I/O devices. They also build timing applications by incorporating timers into their programs.

Table 1. Overview of 3 Weeks Learning Schedule for *ET0917: PLC Applications*

Week	**Week 1**	**Week 2**	**Week 3** ***DT Implementation**
Learning outcomes	PLC hardware architecture and components	Interface common hardware components to PLC	
Lecture (2 hrs/wk)	PLC hardware architecture of a PLC system.	Commonly used hardware used in PLC systems	
Lab (3 hrs/wk)	Familiarization of the whole system Assemble and prepare PLC system for operation	Basic Programming Simple wiring and I/O devices	Introduction to timers and counters applications.

Week 3: By this time, students are expected to understand the basic operations of PLC systems, including hardware architecture, such as the CPU, input/output peripherals, and power supply. They should be able to identify and connect common industrial sensors and

hardware components, address safety considerations using interlocks and overload protection, and understand the IEC 61131-3 standard, including different PLC programming languages like Ladder Logic, Function Block, and Structured Text, as well as variable declarations and addressing modes. This foundational knowledge prepares them to work effectively with simple PLC systems.

Students then progress to learn about Up, Down, and Up/Down counters by creating and testing programs involving these types. To reinforce what is learned, students work on tasks that apply counters in real-world scenarios. However, the primary setup in the lab consists only of a conveyor belt system with standard I/O devices (Figure 1). When tasks involve scenarios beyond the physical setup, students visualize these scenarios using the existing equipment. For example, one learning task requires students to program a car park system with 20 parking lots. Before solving this, students need to first imagine the conveyor belt functioning as a car park, using sensors attached to it (simulated with hand movements) to detect cars entering and exiting (Figure 1). When the car park is full, an LED light on the board indicates its status. This task challenges students to program an Up/Down counter, encouraging them to apply their technical skills while fostering problem-solving abilities when real-world setups cannot be directly replicated.

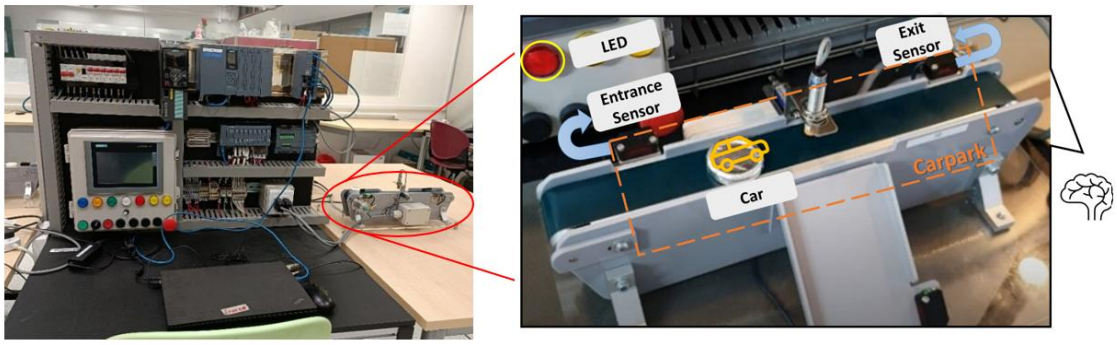


Figure 1. A complete training station meant for 1 to 2 students and how students visualize the carpark scenario in one of the learning tasks in the PLC laboratory.

With prior experience using the basic PLC setup and operations, students are prepared to work with the DT model without the frustration of figuring out basic PLC operations (Sweller, 1988). The introduction of a DT-simulated model of the car park may enhances their ability to visualize operations effectively. Such virtual simulation fosters visual-spatial skills, enhancing problem comprehension, futures thinking, and problem-solving abilities. Gagnon and Landry (2023) demonstrated that visual aids improve spatial knowledge and facilitate navigation in complex environments, supporting the use of simulations in learning contexts. Similarly, Duffy (2016) highlighted that visual spatial thinking is pivotal in problem-solving, aiding the understanding of interactions among system components. Incorporating such simulations into the learning process develops essential visual-spatial skills and encourages anticipatory reasoning and systems analysis, core to futures thinking competency.

Before using the DT virtual model, students follow a series of steps and settings to ensure the physical setup interacts with it. This process requires basic IT technical proficiency and attention to detail. To minimize extraneous cognitive load, strategies such as providing clear, concise, and organized instructions are employed. Techniques like numbering steps and using "red box" emphasize critical actions that need to be followed, as Jamet (2014) demonstrated that visual cues improve learning by directing attention to essential elements. Figure 2

illustrates the application of these methods in the instructions for running the DT virtual model on students' computers.

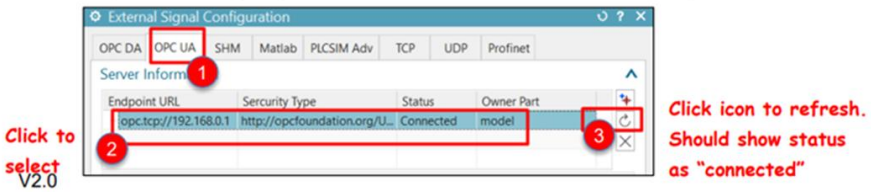


Figure 2. A snapshot of the Instructions for students to prepare for the DT lab.

Once students link the DT virtual model to the physical PLC system at their workstations (Figure 3), they can interact with the virtual models via physical sensors (Figure 1) to develop and test their PLC programs. This integration fosters autonomy by allowing students to explore various programming approaches, enhancing their systems and logical thinking skills.

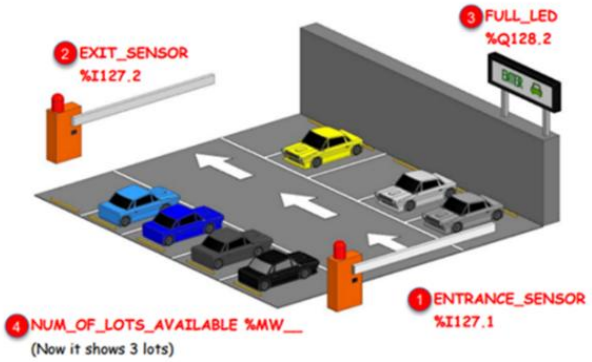


Figure 3. the DT virtual model of the car park task linked to the physical PLC system.

FINDINGS AND DISCUSSIONS

Participants & Instruments Used

The study was conducted with all six classes of second-year DEEE students, totaling 103 participants taking the module in the second semester of the Academic Year 2023/2024. To support the teaching staff and students during the DT lab implementation, two in-house interns who had worked on the DT model were tasked with assisting in the sessions. A mixed-methods approach integrating both quantitative and qualitative data collection methods, including questionnaires, interviews, and observations was adopted to provide a comprehensive understanding of the study outcomes. This approach allowed for a more holistic analysis, capturing not only numerical trends but also deeper insights into student experiences. The questionnaire was conducted using Microsoft Form at the end of the DT lab session, receiving 96 responses (95%). It consisted of twelve 7-point Likert scale items (1 = not true at all to 7 = extremely true), covering four subcategories, as shown in Table 2. Items 1 to 6, adapted from the Intrinsic Motivation Inventory (IMI; http://selfdeterminationtheory.org/), assessed student attitudes. The rest of the items were adapted from Hwang et al. (2013), focusing on the "Perceived Usefulness" and "Perceived Ease of Use" of the technology.

Table 2. Question items and its corresponding subscale.

Item no.	Item content	Subscale	Negative | Neutral | Positive n=96		
1.	I have some choice on how I want to program to complete this task.	Perceived autonomy	5%	22%	72%
2.	I enjoyed the human-Digital Twin interaction experience in this task.	Interest/ Enjoyment	7%	17%	76%
3	I enjoyed working on this task.		8%	13%	79%
4.	Compared to working on the learning task in the traditional setup, the use of Digital Twin increased my motivation for learning.		11%	20%	68%
5.	After working at this task for awhile, I felt pretty competent.	Perceived Competence	12%	26%	62%
6.	I feel I can make sense of the response feedback from the Digital Twin System and correct my program accordingly to make it work as expected.		10%	20%	69%
7.	Using Digital Twin in this task had made my learning easier.	Technology Acceptance	13%	19%	67%
8.	I find it important to keep myself up to date by learning the latest technology such as Digital Twin.		9%	22%	68%
9.	I prefer to use Digital Twin compared to the traditional setup in the lab.		11%	22%	66%
10.	It is not difficult for me to learn to setup the Digital Twin.		12%	27%	61%
11.	I look forward to using Digital Twin in my practical lessons.		13%	20%	66%
12.	I feel I learned better using Digital Twin.		13%	23%	63%

Survey Analysis

For better visualization, a diverging stacked bar chart as seen in Figures 4 and 5 was used to visualize the overall sentiment towards the DT lab.

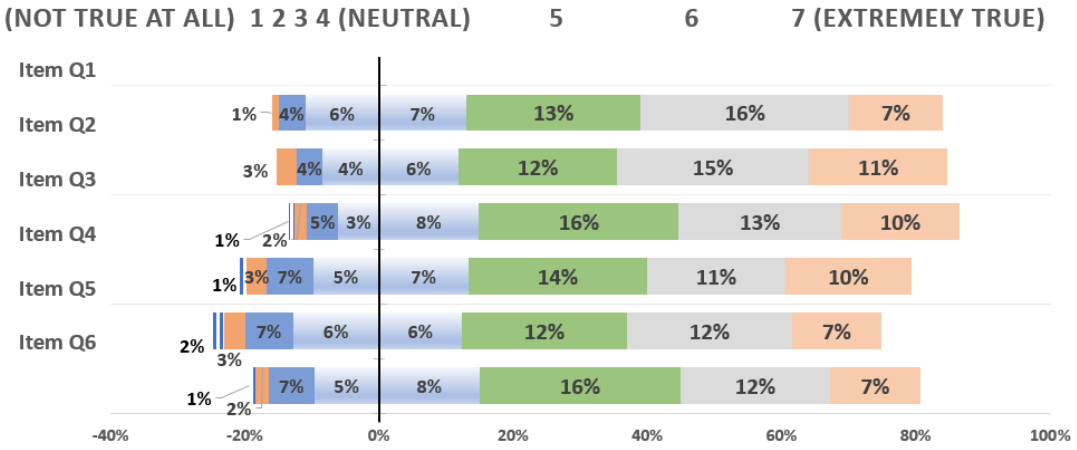


Figure 4. Students' response for Q1 to Q6

As seen, each bar is divided into 8 segments representing all the Likert responses, with a neutral line at zero. Segments to the right indicate positive responses (Likert scale 5, 6, and 7, plus half of the neutral responses), while those to the left represent negative responses (Likert scale 1, 2, and 3, plus half of the neutral responses). For all items 1 to 6, the bars extend more to the right (62-79% of 96 respondents), suggesting high satisfaction. Students generally found the DT technology motivating, valuable, and useful, feeling they had a choice in their learning. This aligns with lab observations. Figure 5 shows that 61-68% of students were positive about DT use in the lab, indicating that DT technology made learning easier,

helped them stay updated with industry trends, and should be used more in future lab sessions. Notably, for some items, no respondents selected rating 1, further reinforcing the absence of strong negative perceptions.

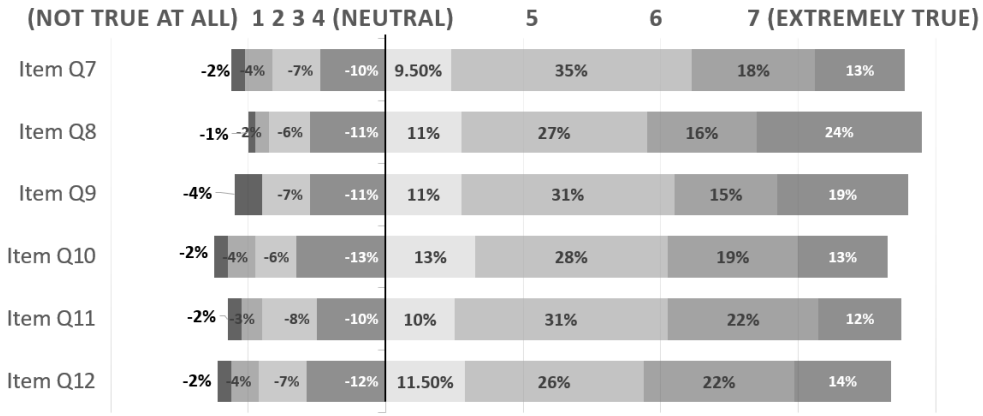


Figure 5. Students' responses for Questions under the subscale of Technology Acceptance.

For greater insight, students were asked to share their personal experiences with the DT lab at the end of the survey. Table 3 presents representative comments categorized by sentiment, based on an intuitive assessment of content and tone. Representative quotes were selected to illustrate each sentiment group. All student responses were reviewed, and examples were chosen to reflect common themes within each category, ensuring a balanced representation of views across positive, neutral, and negative feedback. Out of 96 respondents, 34.7% provided positive feedback, highlighting the ease of visualization and interactive learning benefits. The majority (58.1%) were neutral, possibly indicating indifference or general satisfaction with previous questions. A small portion (5.1%) expressed negative sentiments, citing challenges related to the clarity of the instructions and the usability of the DT.

Table 3. Students' responses to the question – Share your experience with us if you find Digital Twin has impacted your learning in this lab.

Sentiment	No. of student responses	Selected representative comments from students' responses in each sentiment response category.
Positive	34	*"It was fun and interactive".* *"It has made me see it virtually which enhances the learning."* *"It is good that we can keep up with latest technology in school."*
Neutral/Mixed	7	*" With the Digital Twin, it makes understanding of the code easier as it is able to simulate it. However, the connection between the TIA Portal and Digital Twin is unclear as there is no clear sign showing it is connected unlike the TIA portal."* *" I don't think it made much difference but it did make learning and visualising easier."*
Negative	5	*" I find that it's a little harder to learn because I can't see the physical connections so I get confused how or why something gets turned on or off."* *" I didn't quite understand how to use it."*

Face-to-Face Focus Group

Shortly after the survey, a face-to-face focus group discussion with six students was conducted to gain qualitative insights into their experiences with the DT lab. All students shared specific examples of how they enjoyed interacting with the DT technology and how it enhanced their learning. Some examples are shown below:

"Interesting, it is my first time encounter a 3d model that I can use to interact with the actual sensors in the lab".

"It is helpful for my learning as it helps me to see what the PLC is capable of. I can see the actual application in action just like the carpark example."

"It was fun. It was interesting. I have a clear indication of what is going wrong, see the problem and solve it."

To summarize, students appreciated the interactive nature of the DT technology, citing improved understanding of PLC capabilities and enhanced problem-solving through realistic simulations. They recommended more frequent DT labs, additional practical applications, and using DT in short courses to gather industry feedback.

Staff feedback

Immediately following the week when the DT labs were conducted, an online survey were sent to all the four teaching staff members to gather their feedback on the DT lab. The survey included the following four items rated on a 7-point Likert scale (1 = strongly disagree to 7 = strongly agree) as shown in Figure 6.

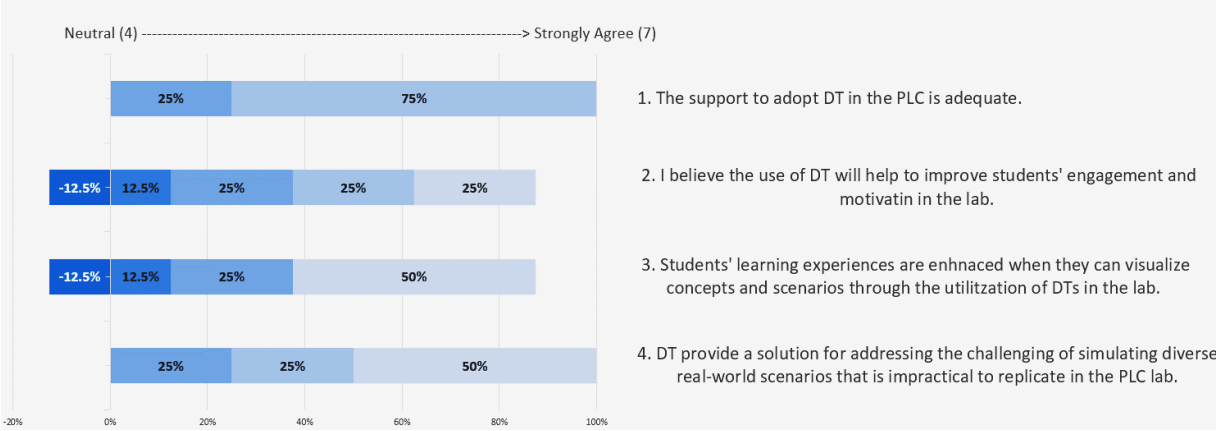


Figure 6. Teaching staff' responses for Questions under the subscale of Technology Acceptance

The bar chart in Figure 6 shows uniformly positive responses from all teaching staff, ranging from neutral to strong agreement, indicating an overall support for DT integration and recognizing its benefits for student learning, engagement, and future potential. Constructive feedback for future improvements were also given. They included students' unfamiliarity with NX software made troubleshooting connectivity with TIA Portal more challenging, first-time DT users required additional time to adapt, and time constraints in the lab posed difficulties.

Addressing Challenges and Future Directions

The main challenge identified from the findings was connectivity issues between the TIA Portal and NX software, which left some students feeling lost and hindered their ability to fully appreciate the benefits of DT activities. Addressing these technical challenges is crucial to enhancing the effectiveness of the DT lab and ensuring all students can fully benefit from DT technology. Since all students were first-time users, providing clear, comprehensive instructions, including troubleshooting tips, can help them resolve issues independently.

Building on the successful implementation of a DT lab activity, the next step is to expand its use by developing additional scenarios beyond the current lab setup. Since DT simulations

allow for the creation of scenarios beyond the limitations of traditional physical setups, activities can be designed to equip students with forward-thinking problem-solving skills. For example, while students currently optimize conventional car park designs, DT models could be used to explore future challenges such as integrating EV charging stations or designing vertical car parks to address urban land constraints. These exercises shift the focus from immediate operational issues to innovative, sustainable solutions, reinforcing a precautionary mindset, an essential aspect of futures thinking. This can help to nurture students' futures thinking competency, preparing them to anticipate and address emerging engineering challenges while strengthening their ability to conceive, design, implement, and operate solutions within the CDIO framework. To ensure meaningful integration, lab activities will align with the module's intended learning outcomes, guided by CDIO Standard 2, while assessments based on CDIO Standard 11 will evaluate learning gains and competency development. By embedding these competencies within DT simulations, students develop the ability to anticipate risks, balance innovation with sustainability, and navigate uncertainties. This aligns with the goals of Education for Sustainable Development (ESD), as highlighted by UNESCO (2017). Further studies will be conducted to assess the long-term benefits of this approach.

CONCLUSION

An in-house Digital Twin (DT) model was developed to simulate a car park scenario in the ET0917 PLC Applications module, enhancing student learning beyond the physical lab's limitations. This DT model was designed with principles from Self-Determination Theory and Cognitive Load Theory to help reduce cognitive load and improve visualization, contributing to more effective learning experiences. Findings from surveys and interviews revealed positive feedback from students and staff, with most students highlighting DT's role in improving visualization and learning. Importantly, this development serves as a targeted educational tool aimed not only at improving students' understanding of current scenarios but also at fostering critical thinking about potential future challenges in engineering. By simulating scenarios that extend beyond the physical lab setup, students can practice anticipating issues and developing solutions, preparing them for the evolving demands of the field. The DT model, while linked to the fixed physical setup in the lab, allows for the inclusion of various scenarios that cannot be physically replicated, thereby broadening the scope of learning and application.

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BIOGRAPHICAL INFORMATION

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STAKEHOLDER ANALYSIS FOR CURRICULUM TRANSFORMATION IN HIGHER ENGINEERING EDUCATION

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ABSTRACT

Curriculum transformation in Higher Educational Institutions (HEIs) is critical to ensure preparedness and responsiveness in an unpredictable world. The research exploring stakeholders' roles and responsibilities in curriculum transformation in HEIs, drew on data generated from a hybrid workshop with partners in an international project. The results highlight the diverse key stakeholders involved in curriculum transformation, and how critical it is to involve them in this complex and dynamic process. The participation of stakeholders is emphasised in several CDIO standards, and their intense engagement is important when considering curriculum transformation.

KEYWORDS

Curriculum transformation, Stakeholders, Engineering Education, CDIO Standards: 9, 12.

INTRODUCTION

Curriculum transformation in Higher Educational Institutions (HEIs) is essential for the development of academic programmes that are relevant, proactive and responsive to the evolving needs of society, industry, and the global workforce (Walker & Bedford, 2017). This is particularly crucial in engineering education, where the curriculum must address the current state of the field and anticipate future challenges and innovations (Audunsson *et al.*, 2024). HEIs should therefore play a pivotal role in preparing graduates for a rapidly changing world (Lee, 2022; Moloi & Moloi, 2024).

Transformation may involve radical changes that impact the long-term sustainability of a programme or institution. Curriculum transformation in HEIs can take various forms and occur at different levels of intensity. It may be in response to formal reviews, accreditation requirements, or the evolving expectations of industry partners and governmental bodies (James *et al.,* 2025). It may also be informed by continuous or ongoing feedback from students and faculty members who make adaptations to integrate emerging trends and new content. A comprehensive stakeholder analysis is critical for meaningful curriculum transformation, which allows for a deeper understanding of the diverse perspectives and interests of those involved in curriculum alignment, relevance and impact (Belita *et al.,* 2020). Stakeholder involvement is fundamental in the CDIO initiative and is formally addressed in some of the Standards. For example, stakeholders should review and validate the learning outcomes of the program (Standard 2) and they should receive feedback on the evaluation of the program with respect to the 12 standards (Standard 12) (CDIO Office, 2025). As expected, the involvement of stakeholders is reflected in several papers within the CDIO community (Matthíasdóttir *et al.*, 2014; Ormazabal *et al.*, 2022).

Engineering stakeholder studies have been conducted over the years, e.g. with focus group discussions (Khoo, Zegwaard & Adam, 2020), surveys (Khoo *et al.*, 2020; May & Strong, 2006), graduates' self-assessment (Grant & Dickson, 2006), semi-structured interviews (Fuentes Del Burgo & Navarro Astor, 2016) and multi-stakeholder studies (Ormazabal *et al.,* 2022). Understanding the roles and concerns of stakeholders is key to reshaping the curriculum, supporting sustainable development and contributing to the future of engineering education. Stakeholders can be defined as "any group or individual who can affect or is affected by the achievement of the organisation's objectives" (Freeman, 1984: 46). Johnson *et al.* (2012) define stakeholders as "… those individuals or groups that depend on an organisation to fulfill their own goals and on whom, in turn, the organisation depends". We can draw on stakeholder theory to acknowledge the importance of considering the needs and interests of diverse stakeholders, and thus aim to provide value creation for those involved (Freeman, 1984). Cheng, Adekola and Sanfa (2022) consider stakeholders for university education studies to be HEIs, students, government and employers. The purpose of this study was twofold: to identify the key stakeholders involved in curriculum transformation and examine their respective roles in shaping the curriculum transformation process.

LITERATURE REVIEW

The curriculum within Higher Education (HE) and HEIs should be transformed to align with the rapidly changing demands of society, industry, and the global context (Opertti, 2023; Bakthavatchaalam, 2024). Traditionally, HEIs prioritised discipline-based knowledge and theoretical foundations, emphasising academic content over practical application. However, recent shifts in workforce requirements and societal expectations have driven HEIs to reassess their curricular frameworks, integrating skills and competencies that enhance

graduates' adaptability and employability (Cheng *et al.,* 2022; Santos *et al.,* 2022; Mabungela & Mtiki, 2024).

Four perspectives may be used to understand curriculum transformation, especially in preparing graduates for a volatile, uncertain, complex and ambiguous (VUCA) world (Walker & Bedford, 2017). Firstly, HEIs incorporate interdisciplinary and more experiential learning opportunities in an effort to transform the curriculum. They are increasingly embracing programmes that blend multiple fields of study, enabling students to develop cross-disciplinary skills and innovative thinking. Such approaches, like those seen in STEM and STEAM (Science, Technology, Engineering, Arts, and Mathematics) initiatives, reflect an understanding that complex, real-world problems often require solutions beyond a single discipline. Furthermore, experiential learning, with internships, co-ops, and service-learning, offers students practical experience, bridging the gap between theory and practice to better prepare them for the job market and operational needs of their future professional activities.

Secondly, digital transformation has significantly influenced curriculum content, structure and outcomes. As technology advances, HEIs are integrating digital skills, data literacy, and online learning components across disciplines. Courses include modules on digital tools, remote collaboration, and data analytics, reflecting the demands of modern workplaces. The rise of online learning platforms and Massive Open Online Courses (MOOCs) has expanded access to education, prompting traditional institutions to offer more flexible, hybrid learning options. The recent advances of generative Artificial Intelligence (AI) is also a key driver.

Thirdly, soft skills and global competencies, such as critical thinking, cultural awareness, and ethical reasoning, are an important focus. HEIs recognise that successful graduates must not only be knowledgeable in their fields, but also be capable of adapting to diverse and multicultural contexts, which is also typified as VUCA.

Lastly, accreditation frameworks (e.g., ABET in the US, ENAEE in the EU, EA in Australia, SASEE in South Africa, or ASEAN Quality Assurance Network (AQAN)) provide some reference and orientation to guide programme leaders in their quality assurance and continuous curriculum improvements, most often based on self-evaluations, complemented by on-site visits. These are external to the quality assurance system of an institution (Patil & Gray, 2009).

More internally for continuous improvements, the CDIO framework provides a flexible opportunity with non-prescriptive standards and tools to align with needs and enhance engineering curricula once its vision is shared (cf. CDIO Standard 1). For each of the 12 CDIO standards, at its higher maturity in the self-evaluation rubric, "evidence related to the standard is regularly reviewed and used to make improvements" (Georgsson, Bennedsen & Kontio, 2016). Stakeholder theory helps us understand how interconnected the various stakeholders are, and how considering stakeholder needs in decision-making can be beneficial in the long run (Freeman, 1984).

As required in CDIO rubrics, key stakeholders, including students, faculty, programme leaders, alumni and working life representatives, should be involved, for example, in formal training programme committees. This stakeholder constellation, though, should be clearly identified in the various processes of curriculum transformation, and should be well trained and skilled for driving and managing curriculum renewal, even in unforeseen conditions. The CDIO Standard 9 on Faculty Competence emphasises that engineering and managerial skills be seen as a system and a whole, with curriculum operating products and their services to learning students. The CDIO Standard 12 on program evaluation guides continuous improvement

processes with maturity scaling in which providing feedback to various stakeholders is included in the processes, allowing for their voice to be heard in evaluation groups (Lassudrie, Kontio & Rouvrais, 2013).

RESEARCH METHODOLOGY

A constructivist paradigm and qualitative approach were adopted to identify the key stakeholders involved in curriculum transformation and to examine their roles in the curriculum development process within HEIs. An online workshop was held with 27 participants from the DECART project (Designing Higher Education Curricula for Agility, Resilience, and Transformation), funded by the European Union, as well as staff from the partner institutions. Mentimer and *'rich picture'* responses were produced by the participants. These responses informed subsequent discussions in groups, to answer the research questions. Jamboard was also used to generate data.

Using Mentimeter as an innovative digital tool allowed for real-time engagement and interaction with the participants, facilitating a sense of connection, given the hybrid workshop. It was also valuable for participants to see first-hand the multiple, diverse responses that came in through the word clouds, facilitating rich discussions. In the first part of the workshop, using Mentimeter, participants responded to the questions: "*Who are the stakeholders who are currently involved in curriculum transformation in HEIs?*", and "*How are the stakeholders involved in curriculum transformation in HEIs?*". Participants could add up to three responses in Mentimeter for each question.

In the second part of the workshop, participants were then asked to draw a '*rich picture*' using Jamboard. A rich picture is a systems thinking tool used to depict a real-world, complex situation and, as argued by Marnewick *et al.* (2024), produce original data. Furthermore, rich pictures are considered standard action research methods, which can give diverse stakeholders a voice (Walker *et al.,* 2014). Participants can gain a shared understanding of the complexities of the situation and better understand the relationships of the stakeholders, as well as their concerns and interests. This study adopted a reflective practice strategy. Data were analysed using thematic content analysis (Anderson, 2007).

STUDY BACKGROUND

The study background is in the context of a European-funded project (DECART: Designing Higher Education Curricula for Agility, Resilience, and Transformation, 2022-25). It involves six HEI partners from member states of the European Union, Indonesia, and South Africa. There are three work packages in the project. Work package one addresses the challenges facing engineering curricula in an increasingly uncertain world and suggests methods and tools for the collaborative conception (C) and design (D) of curricula. The second package analyses the properties of resilient curricula, such as testing them against triggering events that could affect their operating environment (O). The properties of curricula that can increase resiliency are, among others, flexibility, adaptability and redundancy (Waldeck *et al.,* 2024).

Once implemented (I), curriculum operation (O) is dependent on the context, and requires monitoring external and internal changes on a semester or an annual basis, if not over longer accreditation cycles. Change at a low pace means that the curriculum has to be reworked and realigned on this temporal basis. However, the need for change can be more rapid in the face of the pressures of new needs and rapidly disruptive events, as is the case with sudden crises.

The current paper is part of the third work package of the project, which deals specifically with the transformation (T) of a curriculum to better cope with change and align stakeholders around a common vision. Transformation involves engineering moving from one curriculum (current state) to another (future state), whether revised, adapted, recasted, reformed or completely renewed. Transformation entails several degrees, depending on the gap analysis. Transformation involves a significant managerial dimension underpinned by leadership models based on objectives and action plans. In this third work package, a stakeholder analysis is required for HEIs to map their transition from a current curriculum model to a new, more innovative, agile, or robust one. This could contribute to a CDIOT curriculum lifecycle tool.

RESULTS AND DISCUSSION

Stakeholders involved in curriculum transformation

Using Mentimeter, diverse responses were elicited in response to the question: *"Who are the stakeholders who are currently involved in curriculum transformation in HEIs?*" as indicated in Figure 1.

For the participants, the key stakeholders involved in curriculum transformation include students, industry, government, lecturers/teachers/academics, accreditation boards, alumni, deans/leaders/heads, and the community. The words that appear in larger font were added most often.

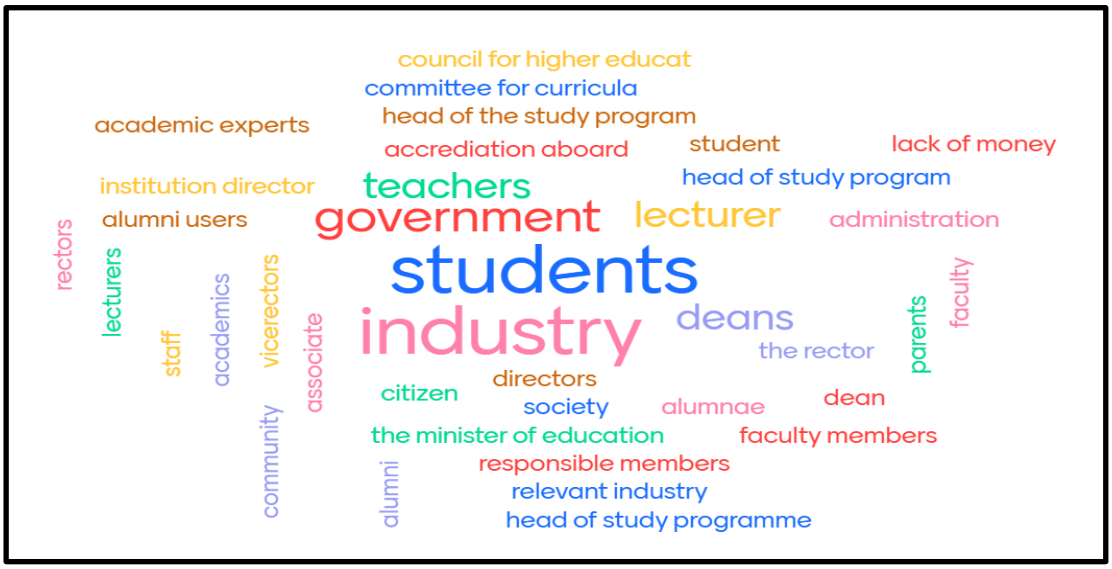


Figure 1. Stakeholders involved in curriculum transformation in Higher Educational Institutions

Curriculum transformation is not the responsibility of a single entity, as highlighted in Figure 1, but a collaborative effort involving multiple, internal and external stakeholders.

The quotations that follow are from the participants, as recorded from the workshop, and their evaluations.

- *"... the main stakeholders, the family and parents, the founders, government policy, relevant industry, academic experts, and the Minister of Education, which is sort of the*

one that covers it all. The ones who affect it are the academic experts, family, and founders."

- *"... faculty members. And then, interestingly, administration. So, the administrators are also involved in the curriculum transformation."*
- *"Other players like faculty members and head of programmes. And also, we were discussing the teacher communities, … keen interest on specific fields like stem fields and so on… the most important were alumni, students, Dean or head of studies programme."*
- *"... Accreditation Board, Provisional Associate, and also the government are those who are responsible for setting some standard or regulation that we should follow. Students, faculty members, committee, rector, vice rector, and also the head of state programme, and also the administration, … who really run the curriculum."*
- *"So here, it seems, there are internal stakeholders and also external stakeholders in the form of industry and government."*
- *"… relevant industry alumni users and also the alumni… given the inputs to the curriculum regarding the demand of the industry or also the technology upgrade."*

Curriculum transformation involves a dynamic, complex and multi-stakeholder engagement process of change and adaptation, and encompasses future demand-induced change that meets future needs. Stakeholder consultation to gather diverse perspectives is critical. The need for constant review and evolution in response to societal, technological, and economic shifts is key, necessitating the inclusion of internal and external stakeholders.

The role of stakeholders in facilitating curriculum transformation

Figure 2 outlines the responses to the question, which was generated using Mentimeter: *"How are the stakeholders involved in curriculum transformation in HEIs?"*.

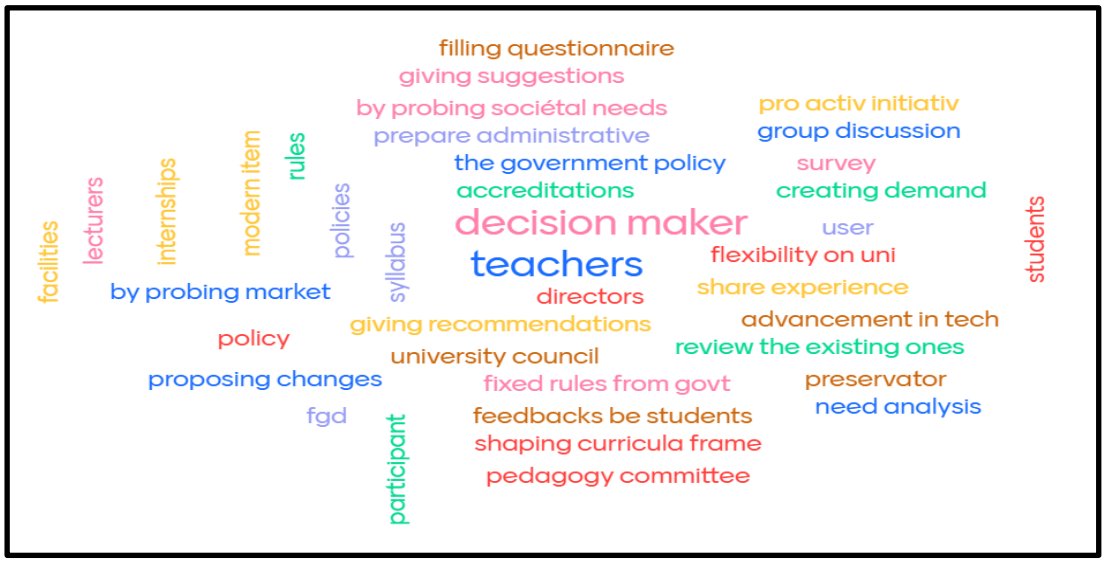


Figure 2. Role of stakeholders in facilitating curriculum transformation in Higher Educational Institutions

The main responses, as per Figure 2, demonstrated the role of the stakeholders as decision-makers, being teachers, dealing with accreditations, probing market and societal needs, creating demand, and giving and implementing recommendations. These stakeholders were found to play a role in shaping curricula, proposing changes, and highlighting societal needs.

- *"... it is not only about involvement, but also about integration… How can we integrate from different views or perspectives?"*
- *"... How important are the stakeholders in this process? And maybe it depends on the study programmes, the university and so on."*

The findings indicate that curriculum transformation is viewed as a complex, multi-dimensional process that integrates innovation, stakeholder engagement, and future-focused learning and thinking. External factors such as regulatory frameworks and societal shifts also play a key role in curricula adaptation to respond to these forces. This holistic view of curriculum development underscores the need for ongoing reviews, inclusive participation, and proactive planning to prepare students for a rapidly changing world.

Participants were also asked to draw rich pictures of the stakeholders involved in curriculum transformation and to depict their concerns and interests. Four rich pictures were generated, as presented in Figure 3, highlighting the diverse perspectives of participants concerning the multiple stakeholders that they identified as key to curriculum transformation.

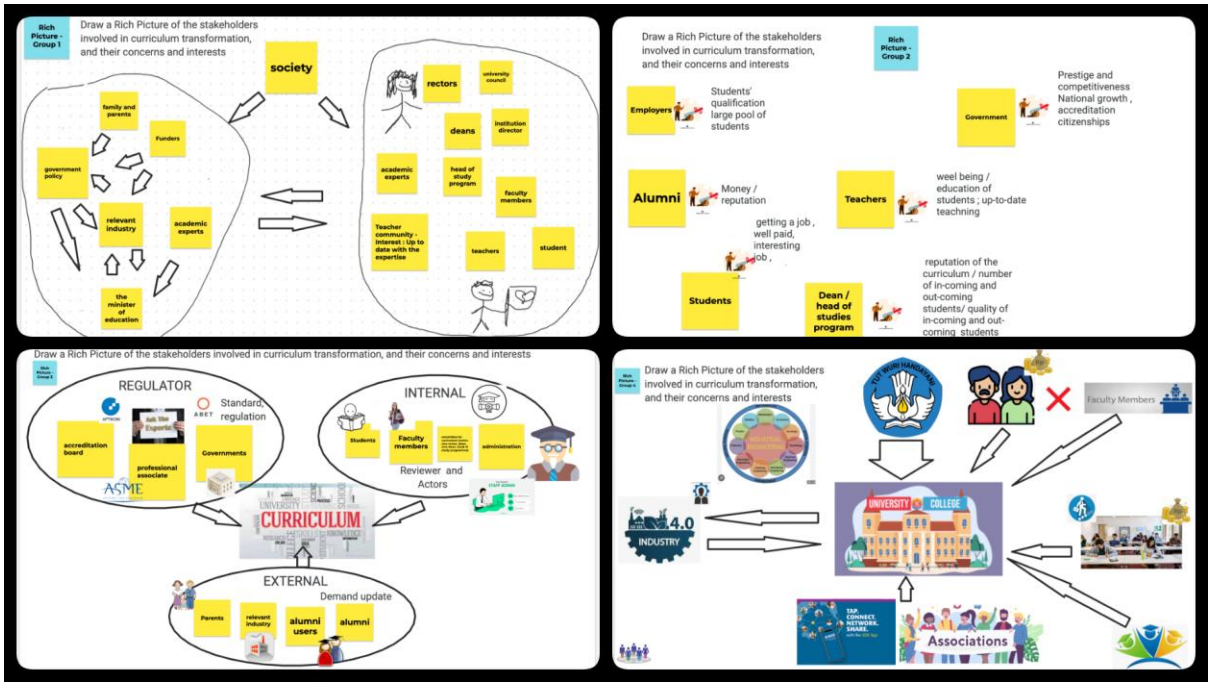


Figure 3. Rich pictures of stakeholders involved in curriculum transformation and their concerns and interests

Curriculum transformation is dynamic and continuous, characterised by its iterative nature in this context, as well as the engagement and collaboration between multiple groups of stakeholders.

- *"We must analyse every stakeholder that must be involved in curriculum transformation."*

The curriculum evolves constantly, incorporating input from various stakeholders to ensure it remains relevant and aligned with contemporary needs. Stakeholders play varied roles in curriculum transformation, providing feedback and suggestions to decision-making, giving policy guidance and conducting needs analysis to influence the design and implementation of curriculum changes. The diverse roles ensure that the curriculum is aligned with both academic and market needs. While stakeholder involvement is crucial, not all stakeholders have equal power or influence, which can lead to disparities in whose needs are prioritised. For example, industry input may drive the curriculum toward a more skills-based approach, while academic experts may push for theoretical depth. Balancing these roles is critical to ensuring that the curriculum remains holistic, addressing both practical job market requirements and broader educational goals like critical thinking, creativity, and citizenship.

The concept of inclusivity and diversity is captured under regulation and brought about by multi-stakeholder and multidisciplinary push factors, implying differing experiences, needs and expectations for curriculum transformation. When curriculum transformation is conceptualised in this frame, the process begins with a critical assessment of whose knowledge is included or excluded. Consultations with diverse communities are conducted, and students varied lived experiences are considered. Practically, this perspective encourages curriculum designers and educators to integrate multiple perspectives into teaching materials, textbooks, and classroom discussions.

Power dynamics play a significant role in determining whose voices are heard and whose opinions shape the process. A multi-stakeholder approach is essential for creating a well-rounded and relevant curriculum. Power imbalances among stakeholders can affect the outcome, as some groups, such as government regulators or industry leaders, may hold more influence than others, such as students or faculty. Curricula may prioritise certain interests, such as employability, over others, potentially marginalising important but less commercially viable areas of knowledge. The challenge is managing diverse inputs to create a coherent, balanced curriculum that meets both educational and professional standards.

- *"... in terms of transformation, the whole aspect of power and the role that the different stakeholders play is something very significant. So, if you're looking at curriculum transformation, think about society, think about the different organisations, think about indigenous, and all those particular aspects…"*

The influence of external actors, such as the government, on higher education and curriculum decisions, could lead to conflicts of interest. Power dynamics in curriculum transformation reveal the complexity of balancing stakeholder interests. The findings point to the significant control that governments and other external bodies have over curriculum content, often overshadowing the input of educators and students. This centralisation of power can stifle innovation and limit the responsiveness of curricula to local or student-specific needs. The discussions of power also expose how entrenched interests, such as those of policymakers or administrators, can prevent meaningful reform. While external regulation may ensure standards and quality, it can also hinder flexibility, making the curriculum less adaptable to new educational paradigms, such as interdisciplinary learning or digital literacy, resisting changes that redistribute power within the educational system, such as giving more voice to students or industry leaders in curriculum design.

- *"... various stakeholders are involved in curriculum transformation, in which each of them has their own purpose and input to the curriculum."*

It is important to gather input from various sources, such as advancements in technology, industry needs, and alumni feedback, to inform curriculum updates. In countries where government regulations dictate curriculum changes, the process can be rigid and top-down, but the inclusion of other stakeholders ensures that the curriculum reflects real-world requirements. Curricula must remain relevant to job market demands. Institutions can bridge the gap between academic learning and professional practice by involving industry experts and alumni. The emphasis on market needs, though, may overshadow educational goals, such as critical thinking, ethical education, or cultural sensitivity. Rigid regulatory frameworks may stifle innovation, limiting the curriculum's ability to evolve in response to emergent trends in education.

- *"It's important that all the stakeholders… to engage them in the process, and to entice the faculty to engage in curriculum transformation… also the quality assurance, relevant associations and external accreditation."*

In highly centralised systems, the government has significant control over curriculum design, leaving little room for flexibility. In contrast, a decentralised approach allows institutions more autonomy. Government involvement ensures that national priorities, such as economic growth, societal values, or political stability, are reflected in education. However, heavy regulation can limit innovation and responsiveness, as institutions may be bound by outdated frameworks that do not reflect current educational needs. The tension between freedom and control is a key issue, as educators and institutions may struggle to balance compliance with regulatory demands, against the need for innovative, flexible curricula that cater to local and global contexts.

Participants indicated that feedback and participation are key in curriculum transformation. They noted that curriculum transformation is compulsory and emergent, imposed versus emergent, and that strong leadership is required.

Figure 4 was developed based on the findings to depict a framework for multi-stakeholder engagement in curriculum transformation in an evolving context.

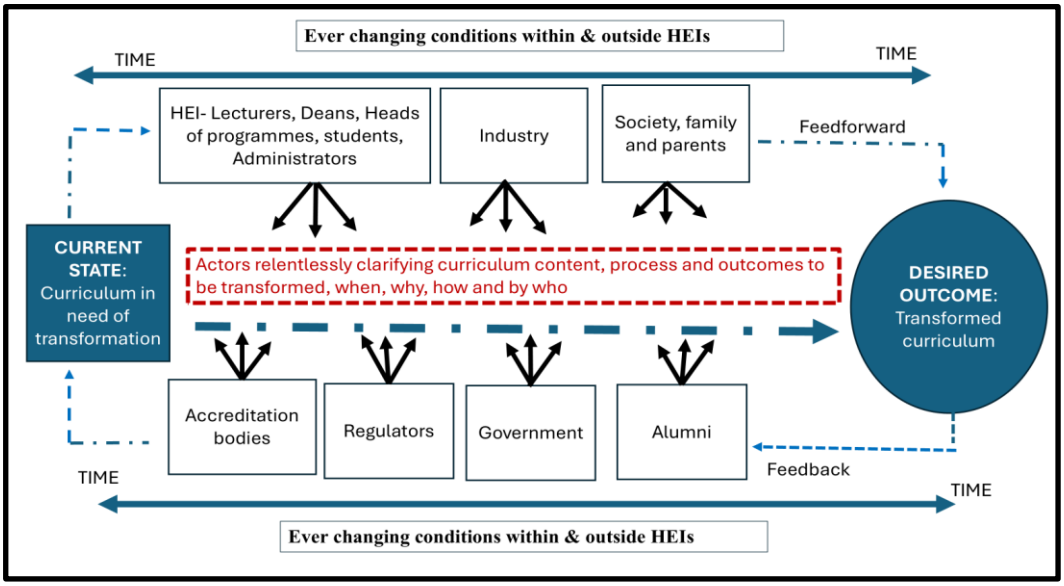


Figure 4. Framework for multi-stakeholder engagement in curriculum transformation. Source: Constructed by the authors.

As indicated in Figure 4, it is important that the curriculum is relevant to societal needs and shapes the transformation process by aligning educational content with pressing societal, economic, and environmental challenges. Collaboration with industry, policymakers, and the community is critical for the curriculum to be relevant to the culture, context and country. Curriculum transformation is time-consuming and iterative, with the engagement of multiple stakeholders relentlessly clarifying curriculum content, process and outcomes to be transformed, when, why, how and by whom in an ever-changing environment, within and outside HEIs, as highlighted in Figure 4.

CONCLUSION AND RECOMMENDATIONS

This study asserts the importance of the participation of diverse stakeholders in HEIs with respect to the curriculum, and the diverse roles and perspectives that need to be surfaced and capitalised on, to ensure education that is relevant, prepared and responsive.

The study highlights the importance of engaging the multiple, diverse perspectives of stakeholders with respect to understanding the curriculum transformation process, and their roles. It is thus critical for HEIs to forge networks to enable diverse stakeholders in engineering education to collaborate and engage for strengthening of the curriculum for the future. The study also highlights the value of employing various innovative digital tools, such as Mentimeter and rich pictures, for relevant rich, real-time data created by the stakeholders. The use of the digital tools provides a valuable systemic perspective highlighting the multiple stakeholders and their diverse perspectives, thereby engaging a complex problem. It also gives a voice to diverse stakeholders in engineering education who may not be considered in curriculum transformation. The study produced a framework (Figure 4) that can be used to drive engineering education by strengthening the networks among the diverse stakeholders involved in curriculum transformation.

The study emphasises the importance of engaging stakeholder analysis to assist HEIs map their transition from a current curriculum model to a transformed curriculum. This analysis informs and guides continuous multi-stakeholder engagement and collaboration within HEIs for effective curriculum transformation. Various stakeholders should be included in curriculum transformation to necessitate a critical review of power and voice in education. The rich pictures generated in the study provide valuable illustrations of how critical it is to consider the elements of power and voice in the curriculum.

Diverse stakeholders who are key in shaping the various curriculum-related activities, as highlighted in the study, resonate with conceiving, designing, implementing, and operating a curriculum model as espoused in the CDIO framework. CDIO Standard 9 on Enhancement of Faculty Competence on the teaching concerns, more at course level, is of importance. For change and transformation management of the whole curriculum, it is important to not only focus on the teaching aspects. The engineering aspects of curriculum, knowledge and skills of curriculum transformation of faculty members should be effective and actionable. System skills, as for products or processes, are an outcome for integrated curriculum architectures, as emphasised by the CDIO Standard 3 principles. An integrated curriculum provides connections between different courses and learning experiences throughout the curriculum. Transformation also involves a significant managerial dimension, underpinned by leadership models for making action and risk plans a reality in accordance with milestones.

The study also highlights the importance of the nexus of curriculum engineering and change management skills of programme leaders, and how vital it is as part of developing faculty competencies, in personal, interpersonal, process, and curriculum-building skills. These need

to be regularly evaluated and updated, where appropriate. CDIO Standard 12 on Programme Evaluation for systematic improvement highlights the need for "documented evidence that programme evaluation methods are being used with key stakeholders, including students, faculty, programme leaders, alumni and working life representatives". Their involvement is best required when systematic and continuous improvements are made to a curriculum, such as between external accreditation cycles, in a reactive manner, even pro-reactive for being prepared for any contingency triggering educational programs. This constellation of internal and external stakeholders (Figures 3 and 4) becomes even more important when considering curriculum transformation rather than their improvements to be ready for uncertain and unpredictable contexts, to reinforce robustness and resilience to destabilising and unforeseen events.

Drawing on the concept of a stakeholder management matrix, a tool used to identify stakeholders with interests and power, it becomes pertinent to analyse the stakeholders, and devise ways of gaining support from relevant stakeholders to ensure that actual curriculum transformation occurs. Within the context of HE, it is evident that executive HEI leaders are the ones with both power and interests. They also have the power to be able to influence and mobilize resources (including financial, human, and technological). It is therefore critical to engage them early on in curriculum transformation efforts, while keeping those stakeholders with power but little interest, well-informed about curriculum transformation.

While the findings of this study provide valuable insights into stakeholder roles in curriculum transformation and highlight the importance of a multi-stakeholder approach, they cannot be generalised to the broader population of stakeholders involved in curriculum transformation. Instead, the findings are only transferable to similar contexts where stakeholder analysis and curriculum transformation are critical. Future research could involve a more diverse pool of participants from various cultural, institutional, and regional contexts to enhance the diversity of perspectives and enrich the understanding of the roles of stakeholders in curriculum transformation in a variety of settings. Future quantitative research is needed to operationalise the proposed framework for multi-stakeholder engagement in curriculum transformation to validate or modify it to enhance its explanatory power and also provide a more nuanced understanding of power relations, resistance to rapid changes, conflicting interests, and the evolving roles of stakeholders in curriculum transformation in a VUCA world.

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GRASPING STRUCTURES: AFFORDABLE HANDS-ON COLUMN BUCKLING ACTIVITY FOR FIRST-YEAR ENGINEERING STUDENTS

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ABSTRACT

Structural mechanics is a fundamental subject in many engineering curricula. Although its disciplinary knowledge is practice-oriented, i.e., aimed at designing structures, it involves high levels of abstraction and mathematical formalism. Consequently, students often struggle to understand the physical reality behind mathematical formulas. To address this challenge in a first-year mechanical design course with 800+ students enrolled, an affordable demonstrator and a scalable hands-on learning activity were developed. The demonstrator and activity introduce students to fundamental concepts of column buckling and structural stability, guiding them in directly observing physical phenomena, interpreting their observations, and linking their discoveries to disciplinary representations. This paper presents the instructional design of the activity, its implementation in a real first-year classroom environment, and an evaluation of its effectiveness in fostering students' understanding of column buckling concepts. 110 students were present in class and participated in the activity. Students' responses to an online quiz indicate that the activity successfully helped them model their observations using disciplinary representations. Survey responses further show that students perceived the activity as increasing their understanding of the topic and appreciated the opportunity to connect theoretical concepts to real-world phenomena. The study presented in this paper serves as a pilot for a broader initiative aimed at developing similar activities for other mechanics concepts. Accordingly, the suitability of the instructional design methodology and the resulting learning activity format are discussed, offering support for engineering educators seeking to develop similar activities for their courses.

KEYWORDS

Mechanics, Engineering Education, Practical Activity, Lab, Conceptual Understanding, Standards: 2, 4, 8, 10

INTRODUCTION

Engineering education often faces the challenge of helping students understand difficult concepts, whose physical meaning is hidden behind abstract and complex mathematical formulas. Hands-On Learning Activities (HOLAs), as a form of active learning, have shown potential in facilitating conceptual understanding [CDIO Standard 8]. However, designing and implementing HOLAs can be daunting, particularly in large first-year bachelor classes (500–1,000 students), due to logistical and financial constraints, combined with a lack of established instructional design methodologies.

To address this challenge, the second author received an educational fellowship to lead an implementation project on “Active Multisensorial Learning in Large Classes” (TUDelft, 2024). The project aims to design a series of small, affordable, and logistically feasible hands-on activities that effectively foster students’ engagement and conceptual understanding. The outcomes of this project are intended to provide practical guidance and examples for other educators at Delft University of Technology (the Netherlands), facilitating the integration of similar activities into their courses [CDIO Standard 10]. This paper presents a pilot study evaluating the suitability and effectiveness of an instructional design methodology for developing hands-on activities in the educational fellowship project. As a starting point, the pilot study focused on a hands-on learning activity addressing the concepts of column buckling and structural stability. The selection of these concepts was primarily a matter of convenience: the second author of this paper was responsible for teaching these topics in an upcoming lecture, making it a practical choice to begin testing the instructional design approach.

At TU Delft, the concepts of column buckling and structural stability are introduced within the first year Mechanical Engineering bachelor curriculum as part of the course "Mechanical Design Project 2" [CDIO Standard 4]. This course, taught in Dutch during the second quarter, enrols approximately 800 students annually. It adopts a project-based approach, where students collaborate in groups throughout the quarter to design a four-wheeled cart, culminating in a competition. In parallel, students attend theoretical lectures on various mechanical design topics, such as material selection, heat treatments, and component sizing. Instead of a textbook, the course provides a formula booklet (Van Beek, 2010) to support the design of mechanical systems. The lectures, held on campus, typically draw an audience of 100 to 200 students. Column buckling is addressed in a single one-hour session during these lectures, with the second author serving as the responsible teacher. The column buckling formulas provided to students in the "Mechanical Design" course are shown in Figure 1.

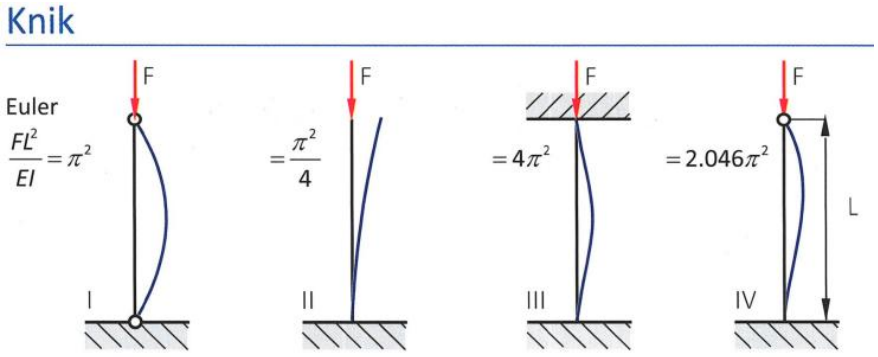


Figure 1 - Disciplinary representations of column buckling [*knik* in Dutch] provided by the formula booklet (Van Beek, 2010)

Column buckling occurs when axial compression acting on a slender structural element exceeds the critical threshold, causing lateral deflection and reducing the load capacity. Below the critical threshold, the column remains stable, but beyond it, the column enters unstable equilibrium, where even minor disturbances can lead to buckling. These concepts are crucial for engineers, who must optimise structural design to prevent or control buckling. Factors such as material properties, length, cross-sectional geometry, and end conditions influence the critical load, which is usually estimated using Euler's formula (Figure 1). While this formula determines the threshold for stable behaviour, it is often mistakenly associated with material strength, such as yield or fracture. However, structural components frequently buckle at loads lower than the yielding point, making buckling an elastic and fully reversible phenomenon. Furthermore, the formulas for buckling do not include material failure parameters, such as yield stress. This ambiguity raises questions about the formula's meaning and its proper application.

Consequently, understanding the phenomenon solely through Euler's formula and the schematics in Figure 1 can be challenging, especially for students with no prior knowledge of these concepts and who have never observed column buckling in real life. Therefore, it was necessary to provide students with the opportunity to directly observe the phenomenon, which was achieved through a hands-on demonstrator. Moreover, the schematics in Figure 1 are "enriched representations" (Fredlund *et al.*, 2014) as they present multiple disciplinary representations (e.g., line and deformed line diagrams, support symbols, force vectors, formulas) layered on top of each other. When introduced to these representations for the first time, students may find certain aspects of the information less accessible or experience information overload. To address these issues, the enriched line diagrams needed to be unpacked—students required guidance to de-rationalize the diagrams and interpret the intended meaning that is not immediately obvious from the representation (Fredlund *et al.*, 2014). To facilitate this process, instructional materials were developed.

Table 1 - Millar's model steps with the related methods and tools used in the pilot study

Millar's model			
Stage	**Name**	**Guiding questions**	**Methods and tools used in the pilot study**
A	Intended learning outcomes	What are students intended to learn from this hands-on activity?	Instructional constructs: • pedagogical affordances • unpacking disciplinary representations
B	Activity specification	What are students intended to do during the hands-on activity?	Instructional design tools: • Lesson plan template • Interactive lecture demonstration approach • M. Gavioli's design principles • Vevox polls, quizzes, and surveys
C	Classroom events	What happened in class? What did students actually do?	Data: • Students' answers to polls and quiz • Independent researcher's observations report • Lesson recording
D	Learning outcomes	What did students actually learn?	Data: • Students' answers to related quiz items and final survey

INSTRUCTIONAL DESIGN METHODOLOGY

The instructional design methodology follows Millar's (2009) sequential model for developing and evaluating practical activities, particularly in terms of "effectiveness." Table 1 presents the model's steps, their guiding questions, and the methods used in this pilot study. Millar defines effectiveness in two ways: "Effectiveness 1" refers to the extent to which the activity successfully guided students in performing the intended tasks, focusing on the relationship between step C and step B. "Effectiveness 2" refers to the extent to which the activity enabled students to achieve the expected learning outcomes, emphasizing the relationship between step D and step A (Millar, 2009).

Methodology for step A: definition of intended learning outcomes

As emphasized also by CDIO [Standard 2], establishing clear intended learning outcomes (ILOs) ensures that all instructional design efforts are focused on achieving the desired educational goals. ILOs are formulated using Bloom's taxonomy levels and domains (Krathwohl, 2002) to ensure they are observable, measurable, and allow evaluation of the activity's effectiveness (effectiveness in sense 2). In this taxonomy, conceptual understanding, the main educational goal of this study, is defined as the ability to abstract from factual knowledge and comprehend the disciplinary core ideas, principles, and their interrelationships (Krathwohl, 2002).

In this study, the construct of "conceptual understanding" follows the definition provided by Gavioli *et al.* (2020) for mechanics. In this discipline, conceptual understanding involves evidence-based and model-based reasoning skills—the ability to model real-world phenomena, as well as to use real-world evidence to generate and refine models. Since models depend on a broad spectrum of representations to fully capture the salient characteristics of phenomena and their interrelationships (Airey & Linder, 2009) effective conceptual understanding also requires representational competence—the ability to interpret and integrate multiple disciplinary representations (Etkina *et al*., 2006). This definition had already been successfully implemented in other two case studies (Uriol Balbin & Gavioli, 2024) (Gavioli & Bisagni, 2021).

The specific intended learning outcomes were defined through an analysis of the disciplinary representations in use, particularly the schematics provided in the formula book, as described in the introduction. This analysis identifies the pedagogical affordances of these representations—what students can learn from them, what needs to be unpacked, and any information gaps (Fredlund, Linder & Airey, 2015). These gaps are then addressed by incorporating tasks into the learning activity that guide students in unpacking the initial representations or engaging with additional ones and the demonstrator.

Methodology for step B: instructional design of activity specifications

Once the ILOs are established, the activity specifications are derived, detailing the tasks students must complete to achieve the intended outcomes. These tasks are observable and measurable, enabling an evaluation of the activity's effectiveness (effectiveness in sense 1). The specifications summarize the lesson plan, activity segments, and instructional materials.

Design of the lesson plan and activity segments

The lesson plan template outlines the lesson's segments, their durations and the needed materials. It is iteratively refined during the instructional design process. In this study, activity

segments follow the Interactive Lecture Demonstration (ILD) approach (Sokoloff & Thornton, 1997), an active learning strategy aimed at fostering student engagement and enhancing understanding of physical phenomena. ILD structures the activity into three phases: predicting, observing, and reflecting. Each segment aligns with the learning objectives, guiding students' attention to key concepts before, during, and after the hands-on activity.

Since the activity aims to foster conceptual understanding, the 'observing' segment's tasks are designed according to the principles of Gavioli *et al*. (2020):

1. Adopt guided inquiry-based instruction.
2. Allow direct experience of phenomena.
3. Incorporate diverse disciplinary representations.
4. Encourage the intertwining of experienced events and theoretical concepts through targeted learning tasks.
5. Monitor and guide students' progression from experience to theoretical models.

Instructional materials using the Vevox platform

For this pilot study, the real-time audience engagement platform Vevox (2024) was selected, as it is available free of charge to TU Delft staff. Three Vevox tools were utilized: *polls,* where students answer questions using their phones as clickers within a set timeframe, with responses displayed live on the classroom screen for immediate discussion; *quizzes*, which allow students to access an online environment via their phones to complete all questions before submission, after which they can view their scores and receive automated feedback; and *surveys*, which function similarly to quizzes but are ungraded. Each of these Vevox tools is implemented in a lesson segment as follows: predict segment – polls; observe/model segment – quiz; reflect segment – survey.

Vevox enables the export of student responses into Excel, facilitating faster data analysis compared to traditional paper-based activity sheets. However, the platform also imposed certain limitations on the types of tasks students could perform, such as the inability to support diagram drawing. Additionally, it was decided to collect students' answers anonymously—no personal data was recorded by the Vevox platform. In this case, the platform assigns each student an identification number, which allows tracking of their performance across different tasks (poll, quiz, survey). These affordances and constraints of the digital platform were considered as additional boundary conditions in the instructional design.

Methodology for step C and D: classroom events and learning outcomes evaluation

Step C evaluates what students did during the session by analysing their anonymous responses to the Vevox poll and quiz. Additional observational data were collected and analysed for this pilot study, including a video recording of the lesson (captured via the university's streaming platform, Collegerama) and written observations from an independent researcher who attended the lecture. These supplementary data collections were used to validate the analysis of student behaviour only for this pilot study. Due to space constraints, the observational data are not detailed in this paper.

Step D evaluates what students learned by analysing their anonymous responses to the Vevox survey. Students rated their perceived achievement of the ILOs and the extent to which the hands-on activity increased their interest in the topic using a 5-point Likert scale (1 to 5 stars). To gain further insights into the learning outcomes, an open-ended question was included. Selected student responses are quoted and commented upon in the results and discussion section.

RESULTS AND DISCUSSION

Step A and B: the designed learning activity

The hands-on column buckling activity was designed to achieve the following goals:

What are students intended to learn from this hands-on activity? (step A, Table 1)

ILO1: Students will be able to recognize observable factors that characterize the buckling behavior and patterns in observations; specifically the relationship between support conditions and both buckling load and deformed shape. *Level 1 – Remember*

ILO2: Students will be able to apply theory (i.e. disciplinary representations) of column buckling to describe real-world experience and observations. *Level 3 – Apply*

ILO3: Students will be able to explain the column buckling phenomenon and its most important aspects. *Level 2 – Understand (overall conceptual understanding of the buckling phenomenon)*

To give students direct experience and insights into the column buckling phenomenon, the second author developed the “column buckling demonstrator,” shown in Figure 2. Designed to minimize cost and enable quick manufacturing, the demonstrator uses common materials from the mechanical engineering faculty workshop, allowing each student in the class to have their own unit.



Figure 2 - Column buckling demonstrator

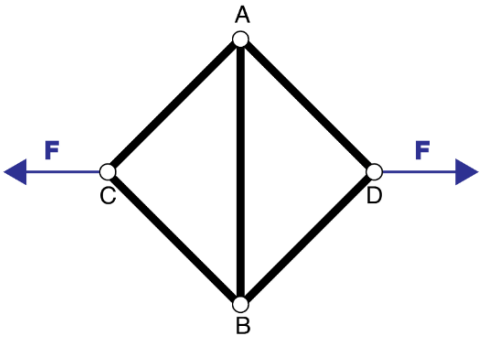


Figure 3 - Analogous mechanism to the buckling load demonstrator

The demonstrator features a 3D-printed ring with slits of varying shapes on its inner edge, which support a slender metal bar. When the sides of the 3D-printed ring are pulled apart, the two supporting points move closer together, as the ring functions as a compliant inverter mechanism (Figure 3). This mechanism converts the applied tensile force, which is much easier for human arms to apply without unwillingly introduce other forces and moments, into the compressive force needed for buckling. The slits in the ring are designed to serve as either fixed or pinned supports, enabling the demonstrator to provide the following support conditions: pinned-pinned, fixed-fixed, and pinned-fixed. Technical drawings and 3D printing files are available upon request from the corresponding author.

Table 2 presents the final lesson plan, outlining the intended learning outcomes for each segment and the materials required to support the activities. The final column of Table 2 provides a summary of the developed instructional materials, which are detailed in full in the Annex to this paper. All instructional materials have been developed in English.

Table 2 – Lesson plan for the hands-on activity on column buckling

Segment	Dur.	Goal	Material	Vevox Items
1. Welcome, introduction to stability and column buckling	20 min	Warm up. Introduce main concepts to be learned (ILO3). ***Predict*** demonstrator behaviour.	Classroom screen: • PowerPoint slides • Vevox Poll Students' personal phone / laptop: • Vevox Poll	***5 polling items (P01-05):*** • 2 about concept of stability • 3 about modelling the behaviour of the hands-on demonstrator
2. Column buckling hands-on activity	20 min	Directly experience column buckling and notice its important aspects (ILO1), ***Observe/model*** (ILO2)	One column buckling demonstrator per (group of) student(s) Students' personal phone/ laptop: • Vevox quiz	***11 quiz items (O01-11):*** • 2 about the student team composition • 6 about reporting and interpreting the observations • 2 only about theory/ modelling • 1 metacognitive
3. Transfer and reflection	20 min	Discussion on exam exercises. Support transfer of learning to new situations for which the concept applies/ ***Reflect*** (ILO3)	Classroom screen: • PowerPoint slides Students personal phone/ laptop: • Vevox survey	***8 survey items (R01-08):*** • 4 Linkert items, 1 multiple choice and 1 open question on perceived learning outcomes • 2 open questions for feedback

Finally, the activity specifications are outlined below as a list of tasks that students are expected to perform during the lesson to achieve the intended learning outcomes.

What are students intended to do during the hands-on activity? (step B, Table 1)
SP1: Actively participate in the polling activity
SP2: Engage with the column buckling demonstrator
SP3: Answer to the observe/model quiz questions
SP4: Correctly report their observations

Discussion on the instructional design of the activity

To ensure students' conceptual understanding, the activity's instructional design follows Gavioli et al.'s principles (detailed in the methodology). Guided inquiry-based instruction (1) is consistently applied throughout the activity, encouraging students to engage in exploration and collect their own observations. They directly experience column buckling (2) using the hands-on demonstrator, bypassing mathematical formulas. Diverse disciplinary representations are incorporated in the activity (3), such as free-body diagrams and illustrations of different end support cases. Targeted learning tasks help students link their direct experiences with theoretical concepts (4), using discipline-specific diagrams and symbols (e.g., types of supports) to record their observations of real-world objects and events. Finally, students' progression from experience to theory is monitored and guided (5) through explicit requests, mostly in the form of multiple-choice questions asking them to "model" or describe their observations. This process follows the usual sequence of engineering modelling and testing: differentiating the body under study from its environment, modelling boundary conditions, applying the load (running the test), recording observations (e.g., the magnitude of the buckling load and comparisons between different cases), and reporting the buckling shape.

Step C and D: classroom events, learning outcomes, effectiveness 1 & 2

In January 2024, the hands-on activity was implemented in the "Mechanical Design" course, with 110 students present in class that day. Students were informed that participation in the data collection was voluntary, anonymous, and not graded. The lecturer then introduced column buckling with slides and engaged students using Vevox polling questions. Students' responses were discussed for clarity. Materials for the hands-on activity were distributed, with minimal instructions provided, and students completed a Vevox quiz either alone or in groups. The lecture concluded with exam tips, though the reflective survey was rushed due to time constraints, which has affected the response rate. In the Annex to this paper, students' responses per each item of the poll, quiz and survey are reported. In the following sections main results are discussed.

What did students actually do during the activity? (step C, Table 1)

SP1: All 110 students logged into Vevox, ensuring full class participation in the polling activity. On average, 83.8% of students responded to the polling questions, with participation ranging from 77.3% to 90%, indicating high engagement. ***SP2:*** Students actively interacted with the column buckling demonstrator, as recorded by the independent researcher. A total of 86 quiz responses were submitted, reflecting a mix of individual and group work. ***SP3:*** The average response rate for the quiz was 78.2%, with nearly all students completing the 'observe' and 'model' items (O03 to O10). ***SP4:*** Students demonstrated strong observational accuracy, correctly reporting their observations 95.6% of the time for 'observe' items (O03, O06, O07, O08, and O09). In the 'model' section, most students correctly identified structural supports: 74 correctly selected a "pinned" support for O04 (9 chose "roller"), and 84 correctly identified the "fixed" support in O05. These results suggest that while students were generally able to model supports, distinguishing between pin and roller types was more challenging. Overall, these results provide compelling evidence that all four intended tasks outlined in the activity specifications (SP1 to SP4) were actually performed.

What did students actually learn? (step D, Table1)

Of the 110 students present in class, 30 completed the reflection survey, which included four Likert scale items, a multiple-choice question (R05), and an open question (R06). The full text items and related responses are in the Annex to this paper. Using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree), students rated their agreement with four statements: R01, R02, and R03 assessed the perceived achievement of ILO1, ILO2, and ILO3 respectively, while R04 measured increased interest in the topic. Figure 4 presents students' responses. 97% of students agreed or strongly agreed that the activity helped them understand column buckling (R03; ILO3). For R01 and R02, 100% agreed or strongly agreed that the activity enabled direct observation of the phenomenon (ILO1) and helped relate theory to experience (ILO2). R04 had the highest neutral and disagreement responses (43%), with 13 students stating the activity did not increase their interest in the topic. The authors suspect this feedback reflects students' general lower motivation for theoretical lessons in a project-based course like Mechanical Design Project 2, where design work and teamwork take priority. This assumption will be explored in future research. Finally, 29 of 30 students reported learning something new from the activity (R05). Sixteen students also answered the open question (R06), providing further insights into the achievement of the intended learning outcomes. Students appreciated new aspects of the phenomenon ('Buckling happens when you compress a beam, and it's easier for the beam to deform in a different direction than the direction of the compression.'), applied theory to describe real-world experience ('Fixed supports need more force than pinned supports to make the beam buckle') and, in general,

understood the its main aspects ('Different supports have different properties and formulas'). The activity also helped students associate the buckling concept with the threshold for stable behaviour rather than material failure (‘Buckling is a phenomenon and not a problem’’ ‘It’s about elasticity’). Overall, the outcomes of step D indicate the activity was effective also in sense 2, i.e. students learnt what they were intended to. The low survey response rate, due to implementation issues in this pilot study, will be addressed by integrating the ‘reflect’ items into the observe/model quiz in future iterations.

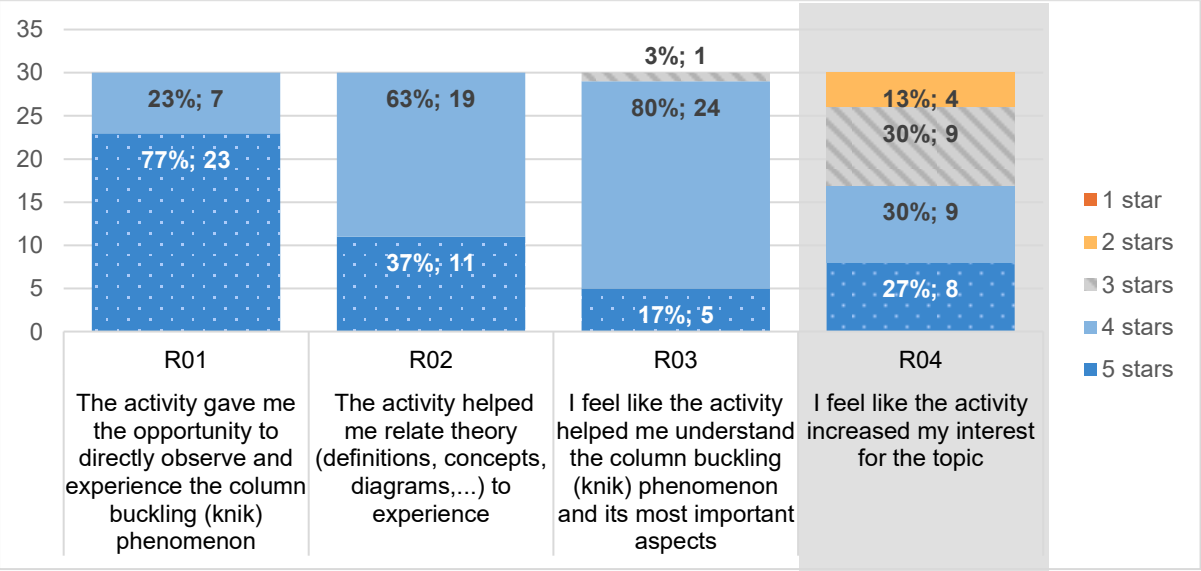


Figure 4 - Students' responses to Likert scale items of the survey.

CONCLUSIONS

The aim of this pilot study was to evaluate the suitability of an instructional design methodology for developing affordable and logistically feasible hands-on activities within an educational fellowship project. These activities aim at fostering students’ engagement and conceptual understanding of mechanics and physics. The learning activity developed for the pilot study introduced first-year engineering students to column buckling in just one hour. The findings confirm that the employed instructional design methodology successfully supports both student engagement and conceptual understanding of the phenomenon. This structured approach is well-suited for scaling up and adapting to other hands-on activities in engineering education, including those planned for the educational fellowship.

Given the positive outcomes of this pilot study, several key lessons can inform the development of hands-on activities for other mechanics and engineering concepts. First, relevant disciplinary representations and their pedagogical affordances must be carefully identified. This ensures the formulation of meaningful and detailed learning objectives. Second, the use of Interactive Lecture Demonstrations, combined with observation and modelling tasks grounded in Gavioli et al.'s principles, provides a clear and structured methodology for designing engaging learning tasks. Specifically, multiple-choice questions formulated in a guided-inquiry style proved particularly effective in guiding students perform real-world observations and link them to theoretical concepts. Additionally, the demonstrator’s low-cost design and the integration of a real-time audience engagement platform ensure scalability to larger class sizes. Finally, comparing activity specifications to classroom events and intended learning outcomes to students’ perceived ones provides a feasible way to

evaluate instructional effectiveness in real classroom settings. Given the challenges educators face in designing hands-on activities that enhance students' conceptual understanding of mechanics, this methodology provides a practical, evidence-based guide that can inspire and support engineering educators.

ACKNOWLEDGEMENTS

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ANNEX 1: INSTRUCTIONAL MATERIAL AND STUDENTS' PERFORMANCE

Table 3 - Transcript of the Vevox polling items and students' responses

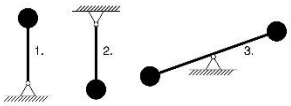
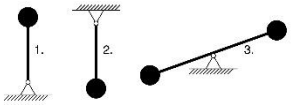
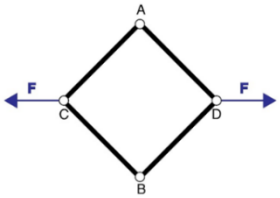
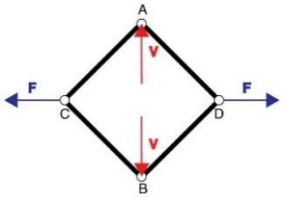
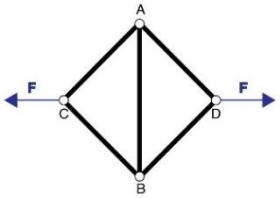
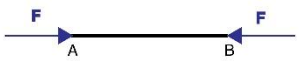
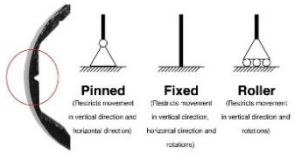
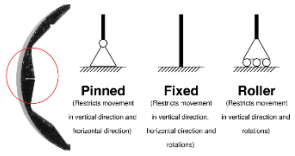
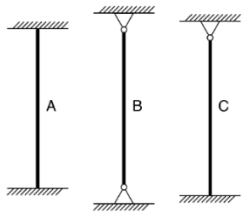
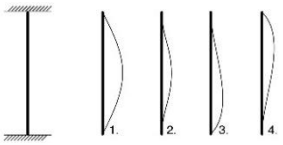
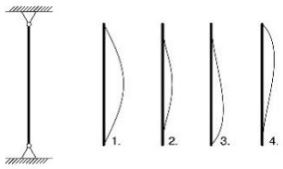
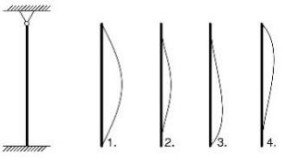
PREDICT SEGMENT					
Nr:	*Type:*	*Question (in **bold** the correct answers):*		*Nr Part:*	*Students' responses*
P01	Multichoice (3 allowed responses)		Which systems are in equilibrium (evenwicht)? System **1, 2** or 3?	99/110 (90%)	**1. System 1: 77 (70%)** **2. System 2: 99 (90%)** 3. System 3: 67 (60.9%)
P02	Multichoice (3 allowed responses)		Which systems are stable (stabiel)? System 1, **2** or 3?	90/110 (81.8%)	1. System 1: 6 (5.5%) **2. System 2: 88 (80%)** 3. System 3: 23 (20.1%)
P03	Multichoice (1 allowed response)		Given that all the beams in this system have equal length, if you pulled point C and D so that they move apart, what would you expect to happen to point A and B? **1. They move closer** 2. They move apart	93/110 (84.5%)	**1. They move closer: 91 (82.7%)** 2. They move apart: 2 (1.8%)
P04	Multichoice (1 allowed response)		What should be the relation between force F and force V to have equilibrium? 1. V should be stronger than F 2. V should be weaker than F **3. V and F should be the same**	94/110 (85.4%)	1. V should be stronger than F: 1 (0.9%) 2. V should be weaker than F: 9 (8.2%) **3. V and F should be the same: 84 (76.4%)**
P05	Multichoice (4 allowed responses)		If you applied a compressing force to this steel slender beam (AB), you would expect it to...(multiple options apply): **1. Shrink**; 2. Elongate; **3. Bend**; 4. Else	85/110 (77.3%)	**1. Shrink: 73 (66.4%)** **2.** Elongate: 5 (4.6%) **3. Bend**: 57 (51.8%) **4.** Else: 20 (18.2%)
Avg.				92,2/110 (83.8%)	

Table 4 - Transcript of the Vevox quiz items and students' responses

OBSERVE / MODEL SEGMENT				
Nr:	*Type:*	*Question (in **bold** the correct answers):*		*Students' responses*
O01	Logistics*	Your group is composed of how many students?		Total sum: 112*
O02	Logistics*	You are answering these questions... 1. only for yourself 2. also for the rest of the group		1.: 34* 2.: 20*
O03	Multichoice (3 allowed responses) Observe		When you apply a compressing force F to the steel slender beam (AB), you can see the beam... 1. Shrinking 2. Elongating **3. Bending**	**Bending: 75/86 (87.2%)** Shrinking: 1/86 (1.2%) **Bending + shrinking: 7/86 (8.1%)** Elongating: 3/86 (3.5%)
O04	Multichoice Model		What type of support does best describe the support this slit provide? **1. Pinned** 2. Fixed 3. Roller	**Pinned: 74/86 (86%)** Fixed: 3/86 (3.5%) Roller: 9/86 (10.5%) No reply: 1/86 (1.2%)
O05	Multichoice Model		What type of support does best describe the support this slit provide? 1. Pinned **2. Fixed** 3. Roller	Pinned: 0/86 (0%) **Fixed: 82/86 (95.3%)** Roller: 4/86 (4.7%)
O06	Rank in correct order Observe		How much compression force is needed to make the beam buckle (knik)? Select the supports configurations (A;B;C) in order, from the one that requires the stronger force to the one that require the weakest. [correct answer: **ACB**]	ABC: 2/86 (2.3%) **ACB: 78/86 (90.7%)** BCA: 5/86 (5.8%) CBA: 1/86 (1.2%)
O07	Multichoice Model + observe		When the beam is between these two supports and the compression force is applied, what shape does it take? shape 1; **shape 2**; shape 3; shape 4	shape 1: 2/86 (2.3%) **shape 2: 84/86 (97.7%)** shape 3: 0/86 (0%) shape 4: 0/86 (0%)
O08	Multichoice Model + observe		When the beam is between these two supports and the compression force is applied, what shape does it take? **shape 1**; shape 2; shape 3; shape 4	**shape 1: 84/86 (97.7%)** shape 2: 2/86 (2.3%) shape 3: 0/86 (0%) shape 4: 0/86 (0%)
O09	Multichoice Model + observe		When the beam is between these two supports and the compression force is applied, what shape does it take? shape 1; shape 2; shape 3; **shape 4**	shape 1: 1/86 (1.2%) shape 2: 0/86 (0%) shape 3: 2/86 (2.3%) **shape 4: 83/86 (96.5)**
O10	Multichoice Observe	Once the compression force was no longer applied, the beam... 1. Returned to the original state (elastic deformation) 2. Remained deformed (plastic deformation)		1.: 86/86 (100%) 2.: 0/86 (0%)
O11	Text Metacognit.	In your opinion, what is the purpose of this hands-on activity?		/

* Quiz items O01 and O02 were designed to track students' decisions and accurately account for responses. A total of 54 quizzes were submitted: 18 by individual students and 36 by students working in groups. Among the group-working students, 15 respondents indicated that they were answering the questions only for themselves. Summing

the numeric answers for O01 resulted in 112 students, suggesting more than one student per group had submitted the quiz. Therefore, the 15 individual responses were counted as separate, while the 21 group responses were multiplied by group size, resulting in 86 students submitting quizzes out of 110 present in class.

Table 5 - Transcript of the Vevox survey items and students' responses

REFLECT SEGMENT			
Nr:	*Type:*	*Question:*	*Students' responses*
R01	Rating 1 - 5 Stars	The activity gave me the opportunity to directly observe and experience the column buckling (knik) phenomenon	4 stars: 7/30 (23%) 5 stars: 23/30 (77%) Average: 4,77 stars
R02	Rating 1 - 5 Stars	The activity helped me relate theory (definitions, concepts, diagrams,...) to experience	4 stars: 19/30 (63%) 5 stars: 11/30 (37%) Average: 4,37 stars
R03	Rating 1 - 5 Stars	I feel like the activity helped me understand the column buckling (knik) phenomenon and its most important aspects	3 stars: 1/30 (3%) 4 stars: 24/30 (80%) 5 stars: 5/30 (17%) Average: 4,13 stars
R04	Rating 1 - 5 Stars	I feel like the activity increased my interest for the topic	2 stars: 4/30 (13%) 3 stars: 9/30 (30%) 4 stars: 9/30 (30%) 5 stars: 8/30 (27%) Average: 3,70
R05	Multichoice	Have you learnt anything new today? yes / no	Yes: 29 (97%) No: 1 (3%)
R06	Text	Can you name the most important thing(s) about buckling (knik) you learnt today, if any?	16 responses; See **Error! R eference source not found.**
R07	Text	Do you have any suggestion on how to improve the activity?	8 responses
R08	Text	Do you have any additional comment?	8 responses

Table 6 - Students' responses to the survey item R06 - open question.

R06: Can you name two of the most important things you learnt today, if any?
1. *Stijfheid [stiffness].* 2. *How support influence it.* 3. *That the knik is the elastic movement, and how big the difference is between support types. The hands on part made that easier to grasp.* 4. *It is only determined by the E value (and dimensions) of the material & changes when the supports are different.* 5. *Buckling happens when you compress a beam and its 'easier' for the beam to deform in a different direction than the direction of the compression. Fixed supports need more force than pinned supports to make the beam buckle.* 6. *It's never 100% accurate because it's an unstable phenomenon.* 7. *That it happens at weaker points.* 8. *It's about elasticity.* 9. *The formulas provided gave me a better understanding of how the various situations in which buckling can occur compare to each other.* 10. *It is the instability of a state and not the actual deformation.* 11. *The shape in which the column buckles is effected by the support.* 12. *Building is knik.* 13. *That buckling is a phenomenon and not a problem. Buckling should be evaluated rather than prevented.* 14. *I learned that different supporters have different resistances (minimum applied forces) for knik and that knik isn't always a negative property/phenomenon.* 15. *Buckling is instable.* 16. *Different supports has different properties and formulas.*

THE CDIO APPROACH TO DEVELOP AI-POWERED FEEDFORWARD SYSTEMS: THE "PROMPT MENTOR"

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ABSTRACT

This study investigates the development and implementation of Prompt Mentor, an AI-powered feedforward tool designed to support students in developing effective prompts in using and engaging critically with generative AI. The tool provides structured, iterative guidance to enhance academic reasoning and writing, and is integrated into an engineering materials course via RMIT's institutional chatbot (VAL). Prompt Mentor was developed in alignment with the CDIO educational framework and ethical standards for secure, scalable deployment within the university's learning environment. Two research questions guided the study: (1) how can Prompt Mentor be integrated into an engineering course to support prompt formulation; and (2) what pedagogical principles enhance reasoning and critical thinking through using such tools? Analysis focused on the quality of student-generated prompts, the use of AI feedback, and evidence of critical engagement in submitted assignments and reflections. Findings indicate that Prompt Mentor supported the development of prompt engineering as a teachable, iterative skill. Students demonstrated an improvement in their ability to frame specific and relevant inquiries and apply AI responses thoughtfully in their academic work. The tool functioned effectively as a feedforward mechanism, encouraging structured inquiry, self-regulated learning and increased confidence, particularly among students from non-English-speaking backgrounds. This study contributes new insights into the pedagogical design and institutional integration of generative AI in higher education. It moves beyond a technical demonstration to provide evidence of learning outcomes and transferable design principles for AI-supported academic development. Our study confirms that Prompt Mentor offers a replicable model for ethically grounded, pedagogically aligned AI tools that can address scalability and inclusivity in engineering education.

KEYWORDS

Engineering Education, Artificial Intelligence, Feedforward, CDIO framework, Standards: 1-3, 7, 8, 11.

INTRODUCTION

In September 2024, Australian International Education enrolled 1,018,799 international students. About half of these international students studied in higher education, and the majority (55%) are from non-native English-speaking backboards (NESB), such as China (22%), India (16%), Nepal (8%), Philippines (5%) and Vietnam (4%) (Department of Education, 2024). While the incoming NESB students have a minimum level of the English language proficiency, many NESB students reported challenges with reading, writing and speaking in academic contexts (Ramjan et al., 2024; Watkins et al., 2012).

In addition, all individuals, irrespective of their physical, cognitive, or mental health status and their life and work commitments, have an equal and fundamental right to education. Yet, students engaged in equitable learning, specifically those with recognized disabilities, chronic illnesses, or mental health conditions as delineated by the Disability Discrimination Act (Australian Government, 1992), alongside those encountering particular life or work circumstances, often encounter unique challenges that can impede educational experiences. As we navigate the fast-changing education environment influenced by technological advancement, it is imperative to identify and implement solutions that foster inclusivity and personalization in learning for all students. Many researchers have contended that universities are responsible for delivering education equitably (Kimpton et al., 2024; McGrath et al., 2023; Mohebbi, 2025).

Given the promising developments in artificial intelligence (AI), specifically ChatGPT, this research aims to investigate their potential and identify areas of improvement in which we can harness the power of AI tools to help students with equitable learning needs. The motivation behind Prompt Mentor is to address the challenges students face when they are studying outside classrooms and lack someone to consult with. Engineering is filled with complex problems, and students often find themselves stuck without timely guidance. Our project aimed to create a solution that leverages AI to deliver structured, personalized feedforward guidance, thereby assisting students in gaining confidence and clarity in their studies. This study was guided by the following research questions:

- How can an AI-powered feedforward tool such as Prompt Mentor be integrated into an engineering course to support students in formulating effective prompts for generative AI use?
- What pedagogical principles and design considerations are essential in developing such a tool to enhance students' reasoning and critical thinking in academic writing?

LITERATURE REVIEW

Feedforward practices

Feedforward practices in education aim to improve student learning by focusing on forward-looking feedback processes that guide students toward better performance in future tasks (Reimann et al., 2019). Unlike feedback, which has traditionally been described as information provided to students based on their past performance, the feedforward process emphasizes the importance of enabling students to improve their work (Scott et al., 2014). According to Dulfer and Akhlaghi Koopaei (2021, pp. 101-102), 'the principle of feedforward is based on developmental comments that guide students to improve work and enhance their knowledge construction rather than focusing on shortcomings of their work'.

The systematic review by Sadler et al. (2023) highlights several key aspects of feedforward practices and their implementation. They found that most feedforward practices (91%) emphasize process and design over mere delivery of feedback as a product. Educators are positioned as instructional designers, creating processes to engage learners with performance-related information actively. It is, therefore, essential to implement feedforward techniques and tools in the classroom to assist students in bridging the gaps between their current performance and their desired outcomes (Dulfer & Akhlaghi Koopaei, 2021).

Common feedforward practices among researchers are: formative assessment approach (Hine & Northeast, 2016; Reimann et al., 2019), interactive and dialogic methods (Beaumont et al., 2011; Ghazal et al., 2018; Hill & West, 2020) and integration with curriculum design (Saeed & Mohamedali, 2022). Many researchers advocate for providing comments on students' drafts before submission. For example, Ghazal et al. (2018) showed that this approach benefits all students, challenging high-achievers and guiding weaker students. Through the dialogue method, educators and students can engage in meaningful dialogue about feedback, where students are informally assessed, which can inform their final assignment (Hine & Northeast, 2016). Feedforward, when integrated into curriculum design, enhances student engagement and performance by embedding forward-looking strategies into teaching and assessment processes. Key features such as timeliness, regularity, active learner involvement, and customized feedback are essential in fostering meaningful academic development (Saeed & Mohamedali, 2022). Saeed and Mohamedali (2022) reported that when integrated systematically into curriculum design, feedforward leads to improved pass rates, higher satisfaction with feedback processes and reduced student anxiety, particularly in the early university years.

Feedforward represents a critical shift in assessment practices, emphasizing proactive and developmental support for students. However, methods for effectively implementing feedforward in large and diverse student groups, such as online or distance learning settings, require further investigation (Baker & Zuvela, 2013). The role of digital tools and AI in facilitating scalable, personalized feedforward strategies has yet to be comprehensively studied.

Technology-Enhanced Feedforward

As recent studies indicate, the integration of AI in education offers transformative potential. AI systems, such as ChatGPT, offer a scalable and efficient method for generating personalized, timely and actionable feedback tailored to students' needs, particularly in open-ended and complex assignments (Jantanukul, 2024; Monib et al., 2024).

AI tools such as ChatGPT have demonstrated the capability to produce detailed, coherent and task-focused feedback (Dai et al., 2023). The utilization of AI ensures timely and consistent feedforward, particularly in large cohorts where traditional methods encounter resource constraints (Ogunleye et al., 2024). AI has been reported to provide support for complex tasks, such as evaluating open-ended assignments, including essays and proposals, and providing comprehensive feedback across multiple domains (e.g., medical education, engineering, and humanities) (Escalante et al., 2023; Malik et al., 2023; Nguyen et al., 2024). According to Dai et al. (2023), AI can generate more readable comments with greater consistency, thereby aiding students in understanding the feedback/feedforward and motivating them to take action for improvement. AI has also shown promising results in promoting self-regulation and critical thinking through iterative feedforward that empowers learners to plan and improve their approaches (Chang et al., 2023; Mohebbi, 2025; Zhou et al., 2024).

Furthermore, AI addresses scalability by automating routine feedback/feedforward processes and supporting diverse student populations with different learning needs, including accessibility and neurodiverse needs (Giannakos et al., 2024; Kamalov et al., 2023). However, strategies must be developed to ensure AI-generated insights support sustainable learning outcomes rather than fostering dependence.

Integration of Generative AI within the CDIO Framework

Effective implementation of feedforward requires careful planning and integration into course design. The CDIO (Conceive-Design-Implement-Operate) framework, widely used in engineering education, provides a systematic approach to developing solutions by balancing theoretical knowledge and practical application (Crawley et al., 2014). In generative AI education, the CDIO framework offers a structured approach to integrating AI tools into engineering curricula while addressing ethical, pedagogical and practical challenges (Saeidlou et al., 2024). This integration aligns naturally with CDIO's emphasis on active learning and real-world engineering experiences.

Recent studies have demonstrated how strategic adaptations of generative AI, particularly ChatGPT, can align with the CDIO framework to enhance education through personalized and active learning experiences (Kimpton et al., 2024; Manna et al., 2024; Saeidlou et al., 2024). Kimpton et al. (2024) specifically evaluated how ChatGPT's capabilities can be customized to support different aspects of the CDIO standards, from technical knowledge acquisition to professional skills development. Their findings suggest that thoughtful integration of ChatGPT can enhance curriculum design by accommodating diverse learning styles and preferences, promoting inclusivity and improved learning outcomes.

Wibawa et al. (2024) further elaborate on this integration by examining how the CDIO framework can be applied to evaluate AI-generated scholarly work. Their research demonstrated that a systematic approach of CDIO can be effectively used to assess and enhance the quality of AI-generated content, particularly in academic publishing.

Implementing AI within the CDIO framework offers promising opportunities to enhance student learning outcomes through strengthened feedforward mechanisms. By examining how generative AI can support active learning, personalized feedforward and real-world problem-solving experiences, we seek to develop evidence-based guidelines for its effective integration into engineering curricula.

METHODS

In the context of this study, Prompt Mentor was designed and developed to support students in generating effective prompts to guide their engagement with generative AI tools. The system provides structured, feedforward support aimed at enhancing reasoning and critical thinking during assignment preparation.

An Overview of the Prompt Mentor: Generative AI Feedforward System into Education

The development of Prompt Mentor involved a systematic workflow designed to align with educational objectives and institutional compliance requirements (see Figure 13). Initially, the objectives for the prompts were clearly identified, preliminary prompts were drafted and tested using ChatGPT to ensure their effectiveness and appropriateness. Following this stage, the RMIT technical team developed the institutional chatbot, VAL, leveraging OpenAI's GPT-4o API (Application Programming Interface). This step was conducted in strict adherence to the

university's security and legal guidelines, ensuring all conversational data were securely stored and managed.

Subsequently, specialized prompts created specifically for Prompt Mentor were integrated into VAL to establish a coherent and interactive virtual persona. The Prompt Mentor was then incorporated into student assessments via the Canvas Learning Management System (LMS), facilitating direct student interaction within a familiar educational environment. Each interaction between students and Prompt Mentor was systematically recorded, enabling detailed tracking of conversations.

The recorded interactions served multiple educational purposes. Primarily, they provided educators with valuable data to assess students' proficiency in prompt engineering, a crucial skill in the context of generative AI tools. Additionally, these records allowed educators to conduct detailed analyses of student engagement and interaction patterns with generative AI, thereby informing further pedagogical refinements and improvements in AI integration strategies.

The workflow adopted for developing Prompt Mentor highlighted the iterative and collaborative approach essential for the successful deployment of educational technology. Each stage—from conceptualization, technical development, compliance assurance and integration within Canvas LMS—required ongoing coordination between educational experts, technology specialists and institutional compliance officers. This structured process ensured Prompt Mentor met educational goals and aligned with institutional requirements for security, data integrity and pedagogical effectiveness.

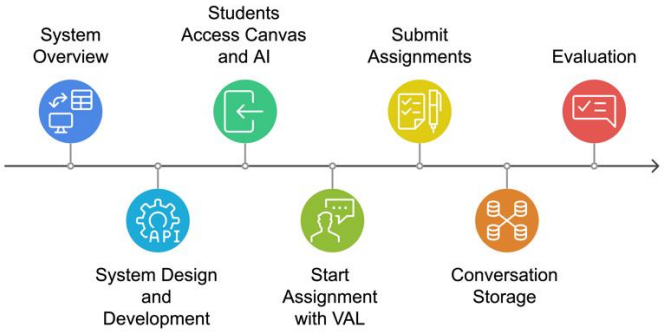


Figure 13. System overview of the Prompt Mentor System: The diagram illustrates the design and development of system prompts, student interactions facilitated through VAL, secure storage of conversations, and an evaluation framework to monitor prompt refinement and student skill development

Personalized Feedback/feedforward with Prompt Mentor

The design and development of Prompt Mentor utilized generative AI, specifically through integration with OpenAI GPT-40 large language model, to create a virtual persona capable of delivering feedback/feedforward. The process started when students input their responses or questions. Prompt Mentor then analysed the prompt, provided suggestions, and offerred an improved version. Alongside this, it provided examples to help students refine their answers (Figure 2). This interactive, AI-driven feedback/feedforward was tailored to accommodate each student's unique learning needs, making the learning experience engaging and customized.

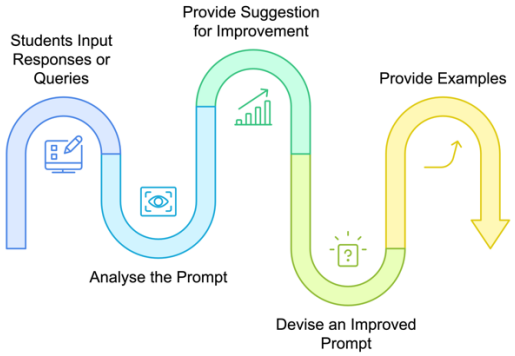


Figure 14. The process of Prompt Mentor in providing interactive responses to students

Align with CDIO Standards

The design and implementation of Prompt Mentor systematically supported all four phases of the CDIO framework. They also adhered to CDIO standards (Johan Malmqvist et al., 2019). ensuring a holistic and structured approach to engineering education. Following Standard 1, Prompt Mentor incorporated real-world contexts by addressing students' challenges when engaging independently with complex engineering concepts, thus supporting the educational experience in practical applications. The tool also supported achieving learning outcomes by enabling students to develop personal and disciplinary knowledge through structured feedback/feedforward and guidance (Standard 2).

Prompt Mentor has been integrated with the curriculum as per Standard 3, combining disciplinary knowledge with self-directed learning and problem-solving skills. It offered integrated learning experiences by embedding critical feedback/feedforward processes into the course design, which helped students connect theoretical concepts to practical applications (Standard 7). Furthermore, the active learning methods promoted by Prompt Mentor aligned with Standard 8, enabling students to actively engage with their learning process through iterative improvements guided by AI-driven personalized feedforward responses.

Finally, Standard 11 was reflected in Prompt Mentor's ability to assess and guide learning in a formative manner, focusing on technical proficiency and broader skills development. By aligning with these CDIO Standards, Prompt Mentor represented a forward-thinking approach that enhances engineering education by integrating innovative AI-driven feedforward mechanisms within a robust curriculum framework.

Case Study: Research Activity on Advanced Metallurgical Topics

The case study was embedded within the Mechanics and Materials 2 course, a core subject offered as part of the engineering curriculum at RMIT University. This course has an enrolment of approximately 250 students each semester. As part of the assessments, students were required to delve into key topics in metallurgical science and materials engineering, equipping them with the knowledge and skills necessary to design components for strength, structure integrity and real-world performance. Students were required to select and research one of five topics (Iron Ore, refining of Titanium, metallic glasses/amorphous metals, Shape Memory Alloys, or Superplasticity), summarizing their findings in a concise, structured response of 600–650 words assay.

Students were given suggested questions for each topic to aid their research, focusing on critical aspects such as material properties, fabrication methods and engineering relevance. A detailed marking rubric outlines the criteria for evaluating technical accuracy, analysis depth and communication clarity. Additionally, students have access to the Prompt Mentor tool within the VAL framework, designed to enhance their inquiry process and optimize the use of AI in developing well-formulated questions.

Qualitative Analysis of Students' Works

The qualitative analysis focused on two primary sources of textual data: (1) questions submitted by students to the Prompt Mentor AI chatbot and the corresponding responses provided by the chatbot, and (2) students' reflective statements about their interactions with the AI and the search strategies they employed. This dual analysis comprehensively understood how students engaged with AI regarding direct interaction and their broader learning processes.

This work analyzed student submissions and chatbot responses, with the aim of evaluating the language used in question formulation, the nature of the AI's responses, and the alignment of feedback/feedforward with educational goals such as critical thinking and problem-solving. In addition, the reflective statements offered deeper insights into students' perceptions of their interactions with the AI, including the effectiveness of the feedback/feedforward they received and the strategies they used to refine their questions or search for information. Common themes, challenges, and patterns in students' questioning were identified, providing valuable insights into the challenges and opportunities students encountered and contributing to broader discussions on effective AI-supported education.

RESULTS

The dataset from this study came from a random selection of ten submitted essays by students who enrolled in the Mechanics and Materials 2 course. We use gender-neutral pseudonyms to preserve anonymity while ensuring clarity when reporting individual student feedback.

The Integration of Prompt Mentor in Learning Management System (LMS)

The implementation of Prompt Mentor into the Mechanics and Materials 2 course was designed to enhance students' interaction with AI by improving their ability to ask effective and focused questions. It was embedded directly within the LMS (i.e. Canvas), where students gained access to the tool that provided immediate feedback/feedforward on their question structure, helping them refine their inquiries and better engage with AI for deeper exploration of mechanics and materials topics (Appendix 1).

Student Interactions with Prompt Mentor

The student's submitted work provided insights into how they interacted with the AI tool (e.g. Prompt Mentor) and their overall perceptions of its functionality and impact on their learning process. Student workflow revealed that AI supported their self-directed learning, where AI facilitated iterative learning by helping students reflect on their queries and refine their approach, contributing to skill development in research and problem-solving. Students progressed from vague, general prompts (e.g. "What is this topic about?") to more specific, structured queries (e.g. "What type of crystal structure does superplastic materials have?"). They also demonstrated a continuous integration of "Prompt Mentor" with other tools (e.g., ChatGPT, search engines) to validate and expand their knowledge, illustrating the AI's role in

enhancing independent learning. An example of how Jordan interacted with Prompt Mentor is shown in Figure 3.

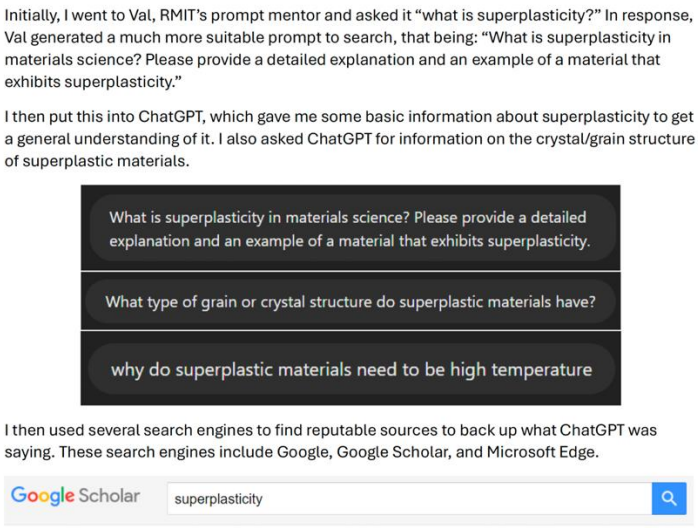


Figure 15. A student's workflow illustrating interaction with Prompt Mentor for query, refinement and integration with external tools for knowledge validation and exploration

Student Reflections

Many students have reported that "Prompt Mentor" provided valuable guidance in formulating effective questions, allowing them to explore complex problems more confidently and engage. Students noted that the tool was handy for comparing how the context level in a question affects the quality of AI-generated responses. Taylor, a student participant, reflected:

When using AI while researching the topic, it was quite easy to phrase questions for the AI, especially when using the Prompt Mentor to compare different responses to questions depending on how much context is provided. ChatGPT's model GPT-4o, even in its lite (free) version, was able to answer questions with intricate detail as well as providing examples and applications of the topic.

DISCUSSION

Implementation and Operation of Prompt Mentor to support students

Integrating Prompt Mentor within the course's digital environment ensured accessibility and ease of use, contributing to its effectiveness as a learning enhancement tool. However, implementing and operating Prompt Mentor required a multidisciplinary approach involving diverse stakeholders to ensure alignment with institutional policies and the CDIO framework. Key stakeholders included technical experts, business analysts, digital experience developers, and strategic leaders across domains such as enterprise technology, education technologies, digital learning experience, and architecture and software engineering.

Prompt Mentor relies on OpenAI's ChatGPT, which introduced controversial institutional considerations, particularly regarding intellectual property (IP), data security and the privacy of students' data. These issues were addressed through careful negotiation and compliance with university policies. The initial process also included consultative meetings with Information Technology Services and legal representatives to address IP and ownership. This

approach aligns with CDIO Standard 1, emphasizing sustainable and ethical practices, and Standard 11, ensuring secure and compliant handling of student data within learning assessment processes. These proactive measures also ensured Prompt Mentor's scalability, enabling its integration into university-wide teaching and learning. Although these activities were not student-led, they were foundational to providing a safe, scalable learning environment that supports responsible engagement with AI across the broader teaching and learning ecosystem.

Utilizing CDIO in AI-Supported Pedagogy

The CDIO framework, as developed by Crawley et al. (2014), promotes engineering education that mirrors the real-world development lifecycle of systems and products. Although the students in our study were not developing physical products, the use of Prompt Mentor facilitated cognitive processes that aligned with the intellectual demands embedded in each CDIO stage. In our study, while students were provided with a predefined problem (e.g., an engineering essay topic or assignment task), Prompt Mentor enabled them to conceive structured prompts that helped them explore and refine their approach to problem-solving. By iterating and refining their prompts based on AI feedback/feedforward, students were able to develop structured and relevant inquiries that enhanced their understanding of engineering concepts. After that, students implemented their AI-assisted inquiry strategies by integrating responses from Prompt Mentor into their writing process, using the generated suggestions to develop structured essays and assignments in engineering. The iterative nature of AI-assisted learning means students continuously interact with the tool, evaluating and refining their understanding through engagement with multiple prompts, similar to how engineers iteratively improve and maintain systems.

Hand-on Learning with AI: CDIO Pedagogy with Prompt Mentor

In our study, the adoption of CDIO framework facilitated a systematic and structured evaluation of Prompt Mentor. The framework focuses on hands-on learning and digital enhancements, ensuring that students are actively engaged while receiving meaningful AI suggestions. For example, the use of Prompt Mentor supported students in refining their questions and also encouraged reflective practices, aligning with the CDIO emphasis on iterative learning and improvement.

These findings resonate with previous research (Saeidlou et al., 2024), highlighting the connection between AI and CDIO-based pedagogy. This approach empowers each stage of the CDIO cycle through the effective integration of technology. In our study, Prompt Mentor played an essential role in the "conceive" and "design" stages by helping students evaluate their ideas and receive formative feedback/feedforward, a process crucial for developing critical thinking and problem-solving skills. Following this, students moved on to the 'implementation' stage, transforming their refined ideas into tangible outcomes, such as essays and written reports. Furthermore, integrating AI tools in the 'operate**"** stage offers significant opportunities to streamline the generation and analysis of required information. By providing students with relevant and accurate data more efficiently and in a shorter time frame, Prompt Mentor helped reduce the overall project duration while enhancing the quality of outputs.

The study also highlighted the importance of creating equitable and personalized learning environments. AI technologies like Prompt Mentor have demonstrated critical in fostering learner autonomy by enabling self-regulated and individualized learning experiences. This outcome aligns with prior findings (Hine & Northeast, 2016; Saeed & Mohamedali, 2022),

emphasizing AI's effectiveness in enhancing writing and grammar skills through personalized, instant feedback/feedforward. Such capabilities empower students to develop foundational skills while tackling complex engineering concepts.

The Prompt Mentor system was designed to support students from diverse linguistic backgrounds. By providing structured, low-risk opportunities for engagement, Prompt Mentor supported students in articulating ideas more clearly and confidently. This aligns with inclusive pedagogical practice and expands the accessibility of high-quality academic support.

Practical Implications for AI-enhanced learning

The study contributed to ongoing discussions on how AI can empower CDIO-based curricula in engineering education by highlighting opportunities and challenges. It demonstrates that AI tools like Prompt Mentor can inform best practices:

- Students benefit from structured guidance in prompt formulation, particularly in navigating open-ended, complex tasks requiring critical thinking.
- Feedforward mechanisms are more effective than post-task feedback in supporting reasoning development, as they allow students to test and refine their thinking prior to submission iteratively.
- NESB students benefited from the AI's support in articulating questions and organizing their ideas, which has implications for inclusive and adaptive learning design.
- The success of such systems depends on the technical model and their pedagogical embedding, including the timing of access, integration with assessment and opportunities for reflection.

CONCLUSION

This study contributes to the growing body of research on AI-enhanced learning by demonstrating how a purpose-built tool like Prompt Mentor can support structured inquiry, enhance student learning through active engagement and promote self-directed learning in engineering education. By integrating generative AI within a secure institutional environment and aligning with CDIO principles, the project offers a model for ethically grounded, scalable innovation.

Beyond its technical implementation, this study demonstrates significant potential in the teachability of prompt engineering, the value of feedforward design and the pedagogical conditions that foster AI-supported reasoning. Students demonstrated their ability to formulate purposeful prompts, engage with AI outputs and apply insights in academic writing—key competencies for future engineers. As engineering education continues to evolve, this work offers a research-informed strategy for integrating AI in ways that extend the CDIO framework to improve how students learn and how they think.

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APPENDIX 1

To make the most out of AI, we have developed a version of VAL, which will help you ask good questions:

Prompt Mentor

Prompto 10:18 AM

Prompt Analysis:

The prompt asks for a definition or explanation of "superplasticity."

Prompt Evaluation:

While the original prompt is clear, it lacks context and does not specify the depth or format of the information required. Adding clear instructions or asking for specific examples could enhance the response.

Example of an Improved Prompt:

"Explain the concept of superplasticity, including its applications in material science, and provide real-world examples that illustrate its importance."

Prompt Engineering Technique Used and Rationale:

The technique used is "Clear Instructions" and "Examples and Templates." By introducing these elements, the prompt encourages a more comprehensive and structured response that includes practical applications and examples, enhancing understanding.

Answer to the Original Prompt:

Superplasticity is a property of certain materials that allows them to undergo significant plastic deformation without breaking when subjected to tensile stress. This phenomenon usually occurs at elevated temperatures and low strain rates. Materials exhibiting superplasticity can elongate to several times their original length, which is advantageous in applications such as the forming of complex metal shapes and parts.

Answer to the Improved Prompt:

Superplasticity refers to the ability of certain materials to undergo extensive plastic deformation under tensile stress without fracturing, typically at high temperatures and specific strain rates. It's utilized in material science for manufacturing intricate metal forms with minimal effort. Real-world applications include the aerospace and automotive industries, where superplastic forming techniques create lightweight, durable parts. For instance, titanium alloys exhibiting superplasticity are used to form complex aircraft components with excellent strength-to-weight ratios, enhancing performance and fuel efficiency.

COMMUNITY-ENGAGED PROBLEM-BASED LEARNING (CE-PBL): PREPARING SUSTAINABLE ENERGY EXPERTS FOR APPLIED CONTEXTS

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ABSTRACT

Community-engaged problem-based learning (CE-PBL) integrates problem-based learning with community engagement to foster experiential, student-centred education. This study evaluates the CE-PBL in a sustainable energy master programme using qualitative feedback from 122 students across 10 cohorts (2002–2020), using hybrid thematic analysis with generative AI. The analysis identifies themes aligning closely with programme objectives and graduate attributes, such as teamwork, technical expertise, and adaptability. Human-machine collaboration using ChatGPT-4 effectively supported data analysis, though the study underscores the essential role of human verification for contextual accuracy. The study shows that the CE-PBL module significantly contributes to developing critical skills in sustainable energy engineering students. However, further research is needed to assess its broader impact.

KEYWORDS

Community-engaged learning, Problem-based learning, Sustainable energy, Thematic analysis, ChatGPT, Course evaluation, Standards: 6, 7, 8

INTRODUCTION

Community-engaged problem-based learning (CE-PBL) is a blended educational approach combining problem-based learning (PBL) with community engagement principles to foster experimental and student-centred learning. This pedagogical method actively involves students addressing real-world challenges in partnership with community stakeholders, blending theoretical knowledge with practical application to solve problems in society. As the combined approach provides an applied context, combining both these approaches has a significant potential to enhance active learning among students, supporting CDIO (Conceive, Design, Implement, and Operate) standard 8.

As an instructional approach (Pluta et al. 2013), problem-based learning (PBL) uses real-world problems as a framework for students to develop problem-solving skills, acquire knowledge, and enhance their ability to work collaboratively. While traditional teaching methods deliver information directly, PBL may encourage students to engage in self-directed learning (Jamison et al. 2014), allowing students to explore solutions to complex, open-ended problems. Hence, PBL can be seen as a conceptual platform for learning (Loyens et al. 2015). For input, PBL requires real-world problems, which are ill-structured, reflecting real-world complexity, see (Holgaard et al. 2017; CDIO 2018). This may help students develop critical thinking skills while applying newly acquired knowledge in a practical context. Consequently, it is a student-centred approach (O'Neill and McMahon 2005), where students are responsible for identifying what they need to learn (CDIO 2009). They find the required resources, and apply knowledge to the problem. Teachers act as facilitators or guides; they support students by asking probing questions, they encourage reflection, and help them stay focused on the learning objectives. PBL is collaborative (Almajed et al. 2016) in the sense that it usually involves group work, which promotes teamwork, improves communication skills, and enhances the ability to view problems from multiple perspectives. Especially important for students from diverse backgrounds and interests, PBL may encourage students to integrate knowledge from different disciplines (Singaram et al. 2011), fostering a more holistic understanding of the problem at hand.

Consequently, in an interdisciplinary engineering programme, PBL can significantly enhance the quality and outcomes of students' learning, thereby enhancing student leadership in engineering education Routhe et al. (2023). It adds real-world relevance (Laur 2013) to a university programme because it emphasises solving complex, real-world problems that inherently require knowledge from multiple disciplines. This may promote the integration of concepts from engineering, economics, management and social sciences. Furthermore, PBL can encourage students to think holistically and understand how aspects of, e.g., the energy transition interact within the energy system, which is at the core of interdisciplinary applications. Because PBL typically involves group work, where students with different qualifications and interests collaborate, they are being prepared for professional settings where interdisciplinary teams are common. Finally, students learn to articulate their discipline-specific knowledge in ways that are understandable to stakeholders, improving communication.

Recent CDIO-based studies explore Challenge-Based Learning (CBL) and project-based service learning, reinforcing CEL's role in engineering education. Norrman et al. (CDIO 2022) highlight collaboration with external stakeholders to tackle real-world challenges, while Puglisi and Domènech-Gil (CDIO 2023) emphasise multiple engagement tools for lifelong learning.

Community-engaged learning (CEL) or service learning, on the other hand, is a pedagogical approach that integrates academic instruction with community-based experiences to foster

civic engagement and deepen understanding of societal challenges. According to Bringle and Hatcher (1996) this method of learning engages in organised service activities that address community needs and foster deeper course understanding, disciplinary appreciation, and civic responsibility through reflective practices.

CEL offers students and academic staff a real-life experience to develop transversal skills, e.g., graduate attributes, enabling communities to gain benefits from publicly funded institutions and connecting universities with public issues (Adshead and Quillinan 2017). For sustainable energy and development in general, we also perceive CEL as a key to addressing complex energy issues elsewhere in society and fostering a just transition.

The integration of service learning within project-based engineering education further strengthens these outcomes. Bielefeldt, Paterson, and Swan (2010) highlight how Project-Based Service Learning (PBSL) enhances technical competencies, cultural competency, and professional skills among engineering students. Their study suggests that PBSL improves student motivation, engagement, and interdisciplinary learning while also meeting accreditation outcomes. However, challenges remain in assessing the long-term impacts of service learning in engineering education (Bielefeldt et al. 2010). Hou (2014) assessed the evaluation of a similar method to evaluate feedback from students of a Master of Public Health (MPH) study programme and identified significant effectiveness of the method.

CE-PBL Approach at the Europa-Universität Flensburg (EUF) for training Sustainable Energy Professionals

The international Master of Engineering programme in "Energy and Environmental Management in Developing Countries" (EEM, 2009-2024) and its predecessor (SESAM, 1999-2009) and successor (SEDev, from 2025) programmes focus on equipping students, primarily from the Global South, with the skills to address global challenges of sustainable energy transition, energy access and development.

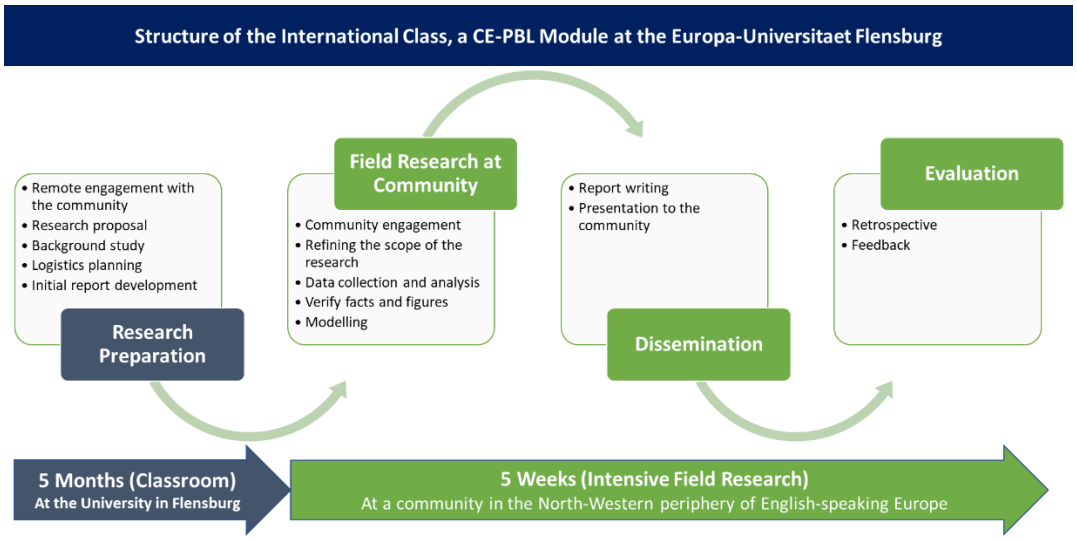


Figure 16: Structure of the CE-PBL module offered by the SEDev department at EUF

A cornerstone of these programmes is the integration of community-engaged problem-based learning (CE-PBL), branded as the International Class (IC) module, designed to prepare students for the real world through applied contexts and interdisciplinary and multicultural professional environments. In the IC module, the CE-PBL approach shifts the traditional role

of professors, placing complex, real-world challenges at the centre of the learning process. Students actively engage with problem-solving exercises during 4-5 week community-based projects, as shown in Figure 16. The module description can be accessed from the university website following the reference (EUF 2025a). These projects focus on developing sustainable local energy solutions through a combination of technical, socio-cultural, and management approaches. The module was introduced in 2002 and rolled out annually. To date, it has been repeated more than 20 times in communities in Scotland and Ireland. A map of all the international classes and reports can be accessed here: (EUF 2025b). Over this period, approximately 260 professionals from more than 60 countries, predominantly from the Global South, were trained through the CE-PBL module, of which about 38% of participants were female. At the end of each project, we have continuously gathered feedback from the students to improve the module in terms of both content and management.

Research Objective and Questions

Aligning with the focus of the study programme stated earlier, the objective of this research is to evaluate the effectiveness of the CE-PBL approach in training sustainable energy professionals based on students' feedback. As the feedback questionnaire was not specifically designed for this research, the approach is to inductively capture themes from the open-ended responses and identify the alignment with programme focus and graduate attributes. The evaluation process is guided by the following research questions:

RQ1: How does the CE-PBL method prepare students for their future careers?

RQ2: What new skills do students acquire through the CE-PBL course to support their career development??

METHODS AND MATERIALS

The feedback questionnaire (FQ) was designed to evaluate the effectiveness of the learning approach among students. It comprised four Likert-scale questions with multiple items and four open-ended questions. However, some questions and their corresponding responses were excluded from this research as they pertained to general management and study location aspects. To evaluate the effectiveness of the CE-PBL module, we utilised a Likert scale with six items and one open-ended question as follows:

FQ1: To what extent (Very much, Much, Hardly, Not at all) do you believe you benefited from different phases and activities of the CE-PBL study module for your future professional work? The activities and phases are (1) research preparation, (2) stay at the study location, (3) introductory session with the community, (4) field research, (5) report writing, and (6) preparing and presenting the findings to the community.

FQ2: What new experiences did you gain during this module, and which of these would you like to incorporate into your future professional work?

Feedback data

In this research, we utilise primary data consisting of students' feedback collected annually at the conclusion of the CE-PBL module, using a consistent paper-based feedback form. Feedback was collected anonymously, and the paper forms were subsequently destroyed in accordance with data privacy policies. To ensure anonymity, no demographic information was gathered due to the small group sizes involved.

Following data cleaning processes, which involved the removal of incomplete or inconsistent entries, feedback from 122 students across 10 cohorts was retained for detailed analysis. Of these, 109 students responded to the open-ended questions, producing an average word count of approximately 20 words per response. It is important to note that a new feedback form was introduced after 2020, and as such, evaluations conducted from 2021 onwards fall outside the scope of this research.

Thematic Analysis

To assess the responses to the open-ended questions, we use a thematic analysis (TA) method inspired from (Braun and Clarke 2006). Figure 17 presents the methodological overview of the TA utilised in this research. A hybrid approach for coding, inspired by (Proudfoot 2023), was adopted. Using this approach, the inductive approach was applied using artificial intelligence (AI) to generate initial codes and themes (Morgan 2023); then the deductive approach was used by the authors upon verifying and updating AI-based coding. As the questions on the feedback form directly asked the students to give feedback on their knowledge and experience gained during the CE PBL module, we proceeded with the values coding approach to identify values, such as beliefs and attitudes expressed in their responses (Saldaña 2009). Parallel to value coding, technical and descriptive coding approaches were also employed to identify knowledge and experiences pertinent to the study domain (i.e., sustainable and renewable energy) and to capture general insights into the students' knowledge and experiences, respectively.

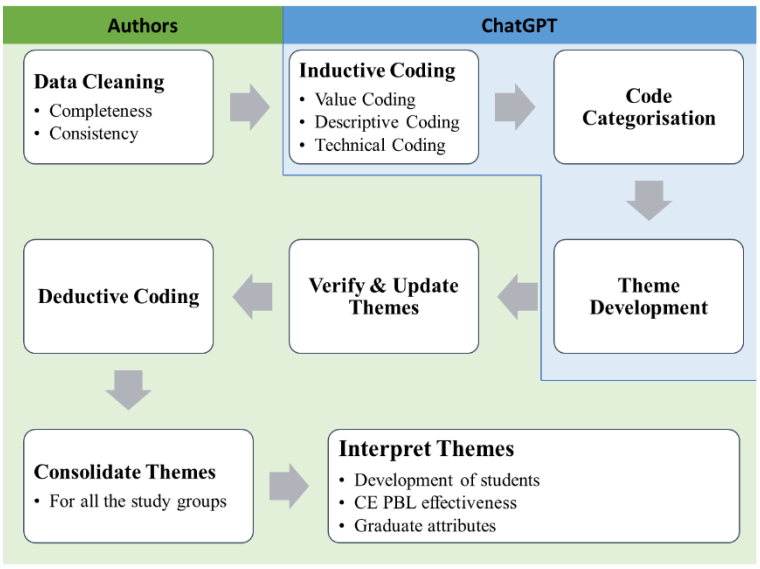


Figure 17: Overview of thematic analysis (Authors' illustration)

Tools

Generative AI-based tool ChatGPT version 4.0 from OpenAI has been used to perform the qualitative research (OpenAI 2025). Several prompts were developed, which were tailored to extract relevant information from the qualitative data to reflect on research questions, as shown in Table 8.

Table 8: ChatGPT prompts for generating initial codes

ChatGPT Prompt	Purpose	Description

Perform inductive coding on the following transcript to generate codes for thematic analysis. To generate codes, use values coding, technical coding and descriptive coding approaches. Highlight codes in the text.	Generate initial codes	It identifies codes using the methodology mentioned in the text and highlights the code in the text, which helps manually verify the coding process.
Develop themes using the codes	Theme develop ment	Identifies broader terms of the codes.

RESULTS

Figure 18 demonstrates the extent to which participants (n = 122) reported benefiting from various components of the CE-PBL study module in preparing for their future professional work. According to the data, most of the participants acknowledged that they significantly benefitted by participating in this module. Combining the values of “Very much” and “Much”, more than 80% of respondents acknowledged benefits from all the phases and activities of the module.

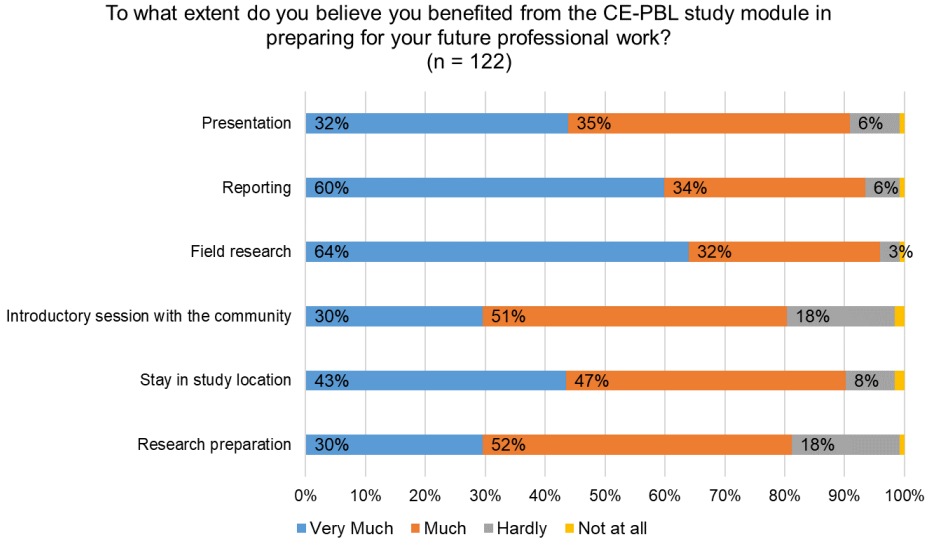


Figure 18: Level of benefit acknowledged by the students

However, a minority indicated no benefits, especially through research preparation and the introductory session with the community, which normally took place during the first week of the 5-week field research phase. The non-benefit expressed by “hardly” and “not at all” for research preparation can be explained by the lack of clarity in research objectives and scope, which is one of the challenges of PBL. Furthermore, some non-benefits can also be explained by heterogenous group dynamics, as there are always students who are more motivated and actively engaged, while others participate less or free-ride. Overall, the findings suggest that practical and research-based components were most beneficial. As the field research component showed the highest benefit, it can be inferred that CE-PBL has a significant impact on transferring knowledge, echoing the effectiveness of the active learning pyramid by Edgar Dale.

Results of Thematic Analysis

The TA was performed on responses to the open-ended feedback question. The analysis of students' feedback on participating in the CE-PBL module indicates the development of new skills and enhancement of existing skills, values, and practical competencies among participants across all 10 cohorts. Table 9 shows the themes identified through the inductive approach and the relevant coding used to develop themes.

Table 9: Inductively identified themes from the thematic analysis

Themes	Codes	Description
Community Engagement	Community development, community energy projects, community engagement	Involves engaging with local communities to develop sustainable energy solutions.
Project Management	Task distribution, project planning, managing deadlines, monitoring and evaluation	Skills related to organising, executing, and evaluating energy projects effectively.
Teamwork and Collaboration	Interdisciplinary teamwork, cultural collaboration, brainstorming, group dynamics	The ability to collaborate in diverse, interdisciplinary, and multicultural teams.
Adaptability and Cultural Sensitivity	Cultural inclusivity, resilience, coping with stress, working in diverse environments	Adaptation to new cultural and working environments while maintaining productivity.
Renewable Energy Systems	Renewable energy, energy demand assessment, wind heat systems, district heating systems	Knowledge and implementation of various renewable energy systems and technologies.
Technical Skills Development	Field measurements, survey development, technical tools (e.g., WindPro), energy audits	Development and application of technical skills specific to sustainable energy engineering.
Sustainable Practices	Sustainability, environmental impact, multidisciplinary energy solutions	Focus on implementing sustainable energy solutions with environmental and societal benefits.

The analysis of student feedback revealed eight key themes: Community Engagement, Project Management, Renewable Energy Systems, Teamwork and Collaboration, Technical Skills Development, Sustainable Practices, Adaptability and Cultural Sensitivity, and Personal Development. The themes underscore the breadth and depth of the CE-PBL approach in equipping students with the skills necessary for careers in sustainable energy and align significantly with the programme focus and objective. Furthermore, these themes also align with the sustainability capabilities and graduate attributes as mentioned in (Thomas and Day 2014) and engineering graduate attributes, as mentioned in (Gutiérrez Ortiz et al. 2021).

Figure 19 shows the distribution of themes across cohorts. According to the results, Teamwork and Collaboration, Community Engagement and Personal Development emerged as significant themes from the quantitative analysis, with the frequency of 40, 33 and 32, respectively, across entire datasets of 10 cohorts. These values also signify the effectiveness of the CE-PBL module in the study programme. Higher frequency in community engagement

shows evidence of tangible experience gained by working closely with communities to develop practical energy solutions and promote local sustainability.

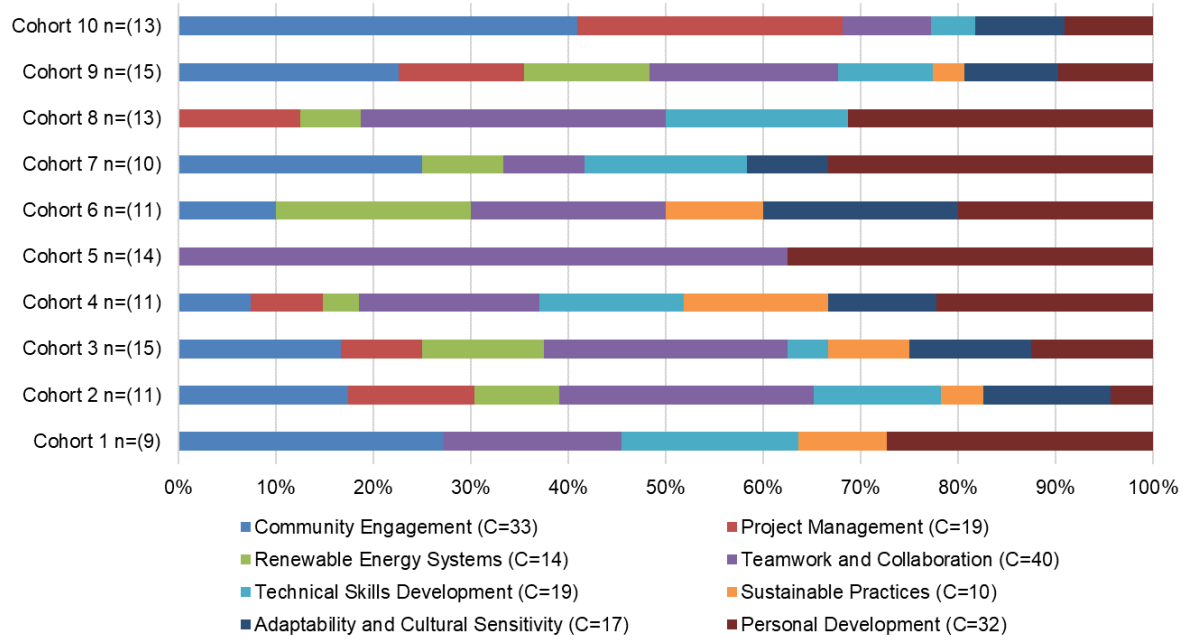


Figure 19: Distribution of acquired skills acknowledged by the students by cohort. Cohort 1 means the oldest, and cohort 10 means the latest cohorts, n = number of respondents in each cohort) and C = frequency of codes representing the theme.

Since each cohort was composed of students from multiple nationalities and cultures, a significant number of students have also acknowledged the development in Adaptability and Cultural Sensitivity, which is very critical for the modern globalised world and to enhance mutual collaboration and cooperation. The Renewable Energy Systems theme showcased the technical expertise students acquired in energy demand assessment, renewable technologies, and system optimisation, providing them with industry-relevant knowledge in the core discipline. Furthermore, the Technical Skills Development theme demonstrated the practical learning outcomes achieved, including the use of tools like WindPro, energy audits, and data analysis techniques. However, it can be observed that the results presented in Figure 19 reveal significant heterogeneity across cohorts. This variability can be attributed to several factors, including the level of cooperation from the communities, the nature of the research topics, and, importantly, group dynamics. For instance, a cohesive group may still derive substantial benefits from a less engaging project, whereas a group experiencing internal conflicts may fail to benefit even from a highly promising project, as observed in several cohorts. Nevertheless, collectively, the identified themes reveal that the CE-PBL is an effective approach for enabling active and student-centric learning in applied contexts.

The quantitative analysis, such as coding and theme generation, was found to be moderately effective with ChatGPT, as reported by Morgan (2023). However, during the verification process of ChatGPT-developed codes and themes, it was found that although ChatGPT helped significantly in developing initial codes and themes, a significant number of transcripts were poorly coded, which emphasises the need for human verification. The verification process added new themes and identified further matches with the themes. It is observed that ChatGPT showed poor performance in tagging community engagement and better performance in tagging themes like teamwork, as community engagement expressions were

latent in the text, while teamwork was mentioned almost directly. On the other hand, as mentioned earlier, the feedback questions were not explicitly designed to measure the impact of the study programme. The thematic analysis conducted on open-ended responses has inherent limitations in accurately identifying and categorising themes. Hence, further research with more targeted assessment methods is required to comprehensively evaluate the effectiveness of the CE-PBL module.

CONCLUSION

In this research, we analysed the effectiveness of the CE-PBL approach in training sustainable energy professionals using students' feedback collected at the end of module delivery. It addresses two research questions using qualitative and quantitative data from 122 students across 10 cohorts. The first research question was explored through benefit-based feedback, with over 80% of students reporting significant positive outcomes. The second research question was addressed through thematic analysis, which identified seven key themes, indicating self-acknowledged development of general and technical skills. These inductively developed themes were aligned well with the programme's objectives as well as general and technical graduate attributes. This study contributes to the body of knowledge by offering evidence of the effectiveness of the CE-PBL learning approach and demonstrating the utility of qualitative analysis supported by human-machine collaboration.

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PREPARING FOR THE FUTURE: ALIGNING ENGINEERING COMPETENCY STANDARDS

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ABSTRACT

The evolving landscape of engineering education necessitates a shift in pedagogical approaches to better prepare graduates for industry demands. The Australian Council of Engineering Deans' (ACED) Engineering Futures 2035 report highlights the defects of current curricula, which emphasise technical skills over professional competencies. To address this gap, the paper explores the newly proposed 'Competency in Professional and Authentic Skills for Success (COMPASS)' framework, which is derived from the Washington Accord and tailored to the Australian and New Zealand contexts. This framework includes 35 sub-skill descriptors across 10 attributes, emphasising the importance of lifelong learning, adaptability, and critical thinking. The aim of the framework is not to propose a new competency structure but an enhancement in language such that all stakeholders may engage. The paper also discusses the integration of feedback literacy and self-agency into the framework, highlighting their role in fostering independent and proactive engineers. The proposed framework aims to bridge the gap between educational outcomes and industry needs, ensuring that engineering graduates are equipped with the necessary skills to thrive in a rapidly changing professional environment.

KEYWORDS

Professional Skills, Graduate Capabilities, Equity & Standards: 1, 9, 10, 12

INTRODUCTION

The Australian Council of Engineering Deans (ACED) Engineering Futures 2035 Engineering Education Programs, Priorities & Pedagogies report has indicated that engineering graduates are currently not going to be prepared for the industry with the current pedagogical approach to engineering education (Crosthwaite, 2021). This is partly due to the traditional engineering curriculum being focused on developing technical skills and placing less emphasis on professional skills. The Engineering Futures 2035 report documented industry perspectives about the pedagogy required to meet the demands by 2035. The report states: “Many industry participants observed that whilst theoretical content is important within the curriculum, future Engineering pedagogy must focus upon replicating the types of environments, projects and settings within which future graduates will work”. Furthermore, Burnett et al. (2021) affirm: “Industry wants to see a re-balancing of the theory-practice components of professional engineering education, with a greater emphasis on practice, including the human dimensions of engineering”.

A crucial aspect of being an industry-ready graduate is the personal and professional skills required to succeed as a professional engineer (Crosthwaite et al., 2018). To graduate with an engineering degree, undergraduate students are required to meet defined graduate competencies/performance standards. In Australia, these competencies are outlined by the Engineers Australia (EA) Stage 1 Competencies (Engineers Australia, 2019), which is based on the International Engineering Alliance (IEA) Washington Accord. However, the EA Stage 1 competencies are specific to Australia, with a more detailed framework for assessing engineering graduates' readiness to enter the workforce by incorporating additional national priorities and expanding on specifics not captured within the WA. In New Zealand, these competencies are defined by the Engineering New Zealand (ENZ) Engineering Performance Standard (which is more directly aligned with the Washington Accord. Whilst EA and ENZ provide the list of competencies required by an engineering graduate, it is equally important that students not only understand what they mean but also that their perceptions of these skills align with industry expectations. As such the WA can be used to define and list the professional skills that an engineering graduate may require.

In a recent systematic literature review of how students, academics and industry priorities professional skills (Quince et al., 2024) revealed that there were differing opinions on their importance between stakeholders across the globe. Several studies state that the competencies outlining the professional skills were difficult to understand as the combination of key tasks or skills within a single competency requires personal interpretation which may be a contributing factor as to why opinions of the stakeholders differ (Hirudayaraj et al., 2021; Munir, 2022; Ortiz-Marcos et al., 2020). The review indicated that no empirical studies offered the viewpoints of all three stakeholders in the same study, highlighting the need for further investigation. It is crucial to align the stakeholders priorities to foster a cohesive and effective engineering education system and to avoid skill gaps, unmet expectations, and insufficient workforce readiness (Quince et al., 2023).

PROFESSIONAL ENGINEERING SKILLS IN EDUCATION

A study by (de Campos et al., 2020) found that 85% of the skills desirable for employability are related to professional skills, while only 15% are technical. Communication and teamwork were ranked in the top quarter of competencies engineers require, based on the perceptions of students, engineers and academics, (Gómez et al., 2021; Khoo et al., 2020; Passow, 2012; Simmons et al., 2021). This data underscores the ongoing need to prioritise the development

of professional skills in engineering programs to adequately prepare graduates for the workforce. Whilst embedding development into the curriculum is crucial, students must understand where their current levels of these skills sit so that over their programs of study, their capacity building can commence. A study by Ramadi et al. (2016) showed that there was a substantial disparity between the perceptions of the importance of professional skills between recent engineering graduates and the industry. Despite the disparity, the study showed that there was no gap between their self-assessed competency levels and the importance they place on those competencies. In other words, students believed they were competent in the areas they believed were important as a graduate. However, this study did not go into detail to evaluate the level of competency the students had suggested. It is clear that the role of engineers and engineering requires a broader professional skillset to deal with the fast-paced modern society. To address this transition, expanding on Ramadi et al. (2016), it would be useful to review the current state by evaluating what professional skills students believe they possess within their engineering programs and the skills and competencies they believe are important for an engineering graduate of the future. To extend further, understanding the educational, dispositional, circumstantial and cultural strengths and inhibitors that influence professional development is key due to the diverse background of engineering students (Quince & Phythian, 2023).

PROFESSIONAL SKILL TERMINOLOGY AND DEVELOPMENT

There is a vast difference in the terminology of professional skills, sometimes referred to as soft (de Campos et al., 2020; Hirudayaraj et al., 2021; Munir, 2022) or transferable (Pinto et al., 2023; Rizzo et al., 2013). Various studies have indicated that there is a difference in understanding what these are, and that wording can be detrimental to these skills. To this end, in this work, we will refer to these skills under a new banner term which captures both the skills and abilities that may be transferable to other fields but also those specific to engineering, ‘professional engineering skills’. This incorporates some skills that have recently be include into the technical skills but are more generic in nature.

This new banner is somewhat novel, it does have previous approaches that have been designed. From the initial version of the CDIO syllabus report they proposed a personal and professional and interpersonal skills diagram. They incorporated professional skills which encompassed problem solving, knowledge discovery and system thinking. This was parallel to teamwork and communication which overlapped, and all encompassed by personal skills. Their justification was “professional integrity and professional behaviour, and the skills and attitudes necessary to plan for one’s career, as well as stay current in the world of engineering” captured by professional skills. “The subset of personal skills which are not primarily used in a professional context, and are not interpersonal, are simply labelled Personal Skills” which included “These include the general character traits of initiative and perseverance, the more generic modes of thought of creative and critical thinking, and the skills of personal inventory (knowing one’s strengths and weaknesses), curiosity and lifelong learning, and time management.”.

It was found that in Australian Universities there is typically one class in the first year of their degree where the majority of the syllabus for the professional engineering skills were mapped against. This was a large, multidisciplinary first year project-based learning class. Common themes included the engineering design cycle, group-based project work and explicit professional engineering skills assessment. Fang (2012) investigated the professional skills developed in a third year technical project based course. Through the highly technical tasks throughout the course, it was demonstrated that communication, entrepreneurship and

teamwork were wall ranked as positive (3/4 Likert scale) through the course survey. Shuman et al. (2005) reviewed how professional skills are taught. Through several high quality implements it was demonstrated that key professional skills are able to be captured by students within PBL courses. It was noted by (Popli & Singh, 2024) that students did not demonstrate skill acquisition until the end of the course when there was a presentation and reflection. Professional engineering skills as teamwork, communication skills, understanding of the design process and self-directed learning were perceived to be improved by students in a PBL course by (Beagon et al., 2019). Picard et al. (2022) showed that PBL was a good method to develop professional engineering skills but only if they are embedded into the project as an explicit task or goal.

This paper presents the consolidated and revised list of competencies that addresses both educational and industry needs. The list of professional engineering skills has been derived from the Washington Accord (WA) but serves also the EA and ENZ professional skills. This framework will be utilised across a multi-institutional, trans-Tasman study. The study which aims to explore students' perceptions and understanding of their professional skills development and readiness to enter the industry. The project aims to identify the strengths and barriers to students' professional skill development. Additionally, the project will explore whether there are differences in the priorities placed on professional skills by students, academics, and industry. This will be achieved by conducting a survey of the students' perceptions of their own professional engineering skills and their rankings.

FRAMEWORK DEVELOPMENT

The WA current competencies were first mapped out and reviewed to get a further understanding of some of the issues that have already be mentioned in the introduction. There are 11 WA's each that have an overarching differentiating characteristic. These differentiating characteristics have a title and a short explanation, these then align to the specific WA. The full table can be seen below in Table 1.

Table 1: Washington Accord Engineer Graduate Attributes

Characteristic Title	Characteristic Overview	Engineer Graduate (WA)
Engineering Knowledge	Breadth, depth and type of knowledge, both theoretical and practical	WA1: Apply knowledge of mathematics, natural science, computing and engineering fundamentals, and an engineering specialization as specified in WK1 to WK4 respectively to develop solutions to complex engineering problems
Problem Analysis	Complexity of analysis	WA2: Identify, formulate, research literature and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences with holistic considerations for sustainable development.
Design & development of solutions	Breadth and uniqueness of engineering problems i.e., the extent to which problems are original and to which solutions have not previously been identified or codified	WA3: Design creative solutions for complex engineering problems and design systems, components or processes to meet identified needs with appropriate consideration for public health and safety, whole-life cost, net zero carbon as well as resource, cultural, societal, and environmental considerations as required.

Investigation	Breadth and depth of investigation and experimentation	WA4: Conduct investigations of complex engineering problems using research methods including research-based knowledge, design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.
Tool Usage	Level of understanding of the appropriateness of technologies and tools	WA5: Create, select and apply, and recognize limitations of appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to complex engineering problems.
The Engineer and the World	Level of knowledge and responsibility for sustainable development	WA6: When solving complex engineering problems, analyze and evaluate sustainable development impacts* to: society, the economy, sustainability, health and safety, legal frameworks, and the environment.
Ethics	Understanding and level of practice	WA7: Apply ethical principles and commit to professional ethics and norms of engineering practice and adhere to relevant national and international laws. Demonstrate an understanding of the need for diversity and inclusion.
Individual and Collaborative Team work	Role in and diversity of team	WA8: Function effectively as an individual, and as a member or leader in diverse and inclusive teams and in multi-disciplinary, face-to-face, remote and distributed settings.
Communication	Level of communication according to type of activities performed	WA9: Communicate effectively and inclusively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, taking into account cultural, language, and learning differences.
Project Management and Finance	Level of management required for differing types of activity	WA10: Apply knowledge and understanding of engineering management principles and economic decision-making and apply these to one's own work, as a member and leader in a team, and to manage projects and in multidisciplinary environments.
Lifelong learning	Duration and manner	WA11: Recognize the need for, and have the preparation and ability for i) independent and life-long learning ii) adaptability to new and emerging technologies and iii) critical thinking in the broadest context of technological change.

Each of the WA have multiple aspects that can be quite multidisciplinary and broad in nature. An example of this is seen below in Table 2.

Table 2: Example Washington Accord Attribute Displaying Difficulty in Understanding

Differentiating Characteristic	Engineer Graduate
Project Management and Finance Level of management required for differing types of activity	Apply knowledge and understanding of engineering management principles and economic decision-making and apply these to one's own work, as a member and leader in a team, and to manage projects and in multidisciplinary environments.

Breaking down this characteristic and WA, shows that both knowledge and understating of management principles, economic decisions and application in individual, leader of team and management of multidisciplinary environments. When investigating what a graduate may be required to undertake, management and leading may not be directly applicable when first entering the workforce, as such this interpretation may lead to an incorrect prioritisation of various stakeholders. This is but one interpretation with one example, demonstrating the difficulty in applying and interpreting the competencies. There were all but one of the 11 WA's that were not classified as a "professional engineering skills" which was engineering knowledge. Whilst the overarching characteristic could be seen as a professional engineering skill, the WA explicitly states that it is the foundational mathematics and science knowledge. This does not align with the studies work and is thus omitted from the remainder of the study. The expansion and simplification of the WA's was undertaken by critically reviewing the detailed attributes or indicators of required skill. Each of these were first extracted from the WA's explicitly to generate a large table of skills that were found within the framework but may have required simplification in characteristics. We classified 35 skill sub-descriptors that was determined to be the most direct and explicit explanation of the skill. An example of this expansion is seen in the below table (3).

Table 3: Example of Development of Framework from the Washington Accord

Attribute: Lifelong learning	Sub skill descriptors
WA11: Recognize the need for, and have the preparation and ability for i) independent and life-long learning ii) adaptability to new and emerging technologies and iii) critical thinking in the broadest context of technological change (WK8)	Undertake independent and lifelong learning to grow professionally.
	Adapt to emerging technologies in the engineering field.
	Develop critical thinking to navigate technological change.

This process was undertaken by all three authors where there was consensus and agreement based on both the wording and descriptor. This generated a list of 10 attributes that directly aligned with the 10 WA's however there were 35 individual sub-skills descriptors creased. The EA stage 1 was consulted as well as current literature (Cajander et al., 2011; Litchfield et al., 2016; Quince et al., 2024) to derive the language and the descriptors. The research team also included missing indicators or skills which were added to the relevant skill level. There were several that were originally flagged for inclusion however the majority ended up being assumed or included within sub-skill descriptors. There were three skills that were covered but either not explicitly or the team felt that they were not emphasised enough. They were the use of GenAI, self-agency and feedback literacy, these will be discussed in the following section. The framework which is described as Competency in Professional and Authentic Skills for Success (COMPASS) can be seen in Table 4.

Table 4: Professional Engineering Skills Framework Based on the Washington Accord

Skill Descriptor	Code	Skill Sub-Descriptor
Ability to Define and Analyse Engineering Problems	1.1	Identify, analyse, and solve complex engineering problems supported by evidence.
	1.2	Solve engineering problems with sustainability and holistic perspectives in mind.
Ability to Design and Develop Engineering Solutions	2.1	Design innovative engineering solutions to meet project needs.
	2.2	Develop solutions considering public health and safety.
	2.3	Develop solutions considering project lifecycle, costs, and societal impacts.
Ability to Methodologically Investigate Engineering Problems	3.1	Design experiments, analyse and interpret data, and synthesise information for valid conclusions.
	3.2	Use research methods to investigate complex engineering problems.

Ability to Use Engineering and Digital Tools	4.1	Identify suitable modern tools and techniques, understanding their strengths and limitations
	4.2	Select suitable modern tools and techniques, understanding their strengths and limitations
Ability to Solve Complex Engineering Problems with a Focus on Responsible and Sustainable Outcomes	5.1	Evaluate the sustainability of engineering solutions.
	5.2	Assess the socioeconomic impacts of engineering practices, decisions, and solutions.
	5.3	Analyse health and safety concerns in engineering practices.
	5.4	Consider environmental impacts in engineering decisions.
	5.5	Understand relevant legal frameworks in engineering.
Ability to Apply Ethical Practices	6.1	Adhere to relevant national and international laws and regulations.
	6.2	Demonstrate an understanding of diversity and inclusion.
	6.3	Uphold ethical standards and professional norms in engineering.
Ability to Work Independently and Collaboratively	7.1	Receive feedback, evaluate its relevance, and take necessary action.
	7.2	Provide constructive feedback.
	7.3	Contribute effectively as a team member.
	7.4	Lead teams effectively.
	7.5	Perform self-directed tasks.
	7.6	Collaborate in diverse and multidisciplinary environments.
Ability to Communicate Through Various Mediums	8.1	Communicate effectively within the engineering community.
	8.2	Communicate effectively with society.
	8.3	Develop reports and presentations that respect cultural and linguistic diversity.
Ability to Apply Project Management Skills	9.1	Apply financial decision-making to individual engineering projects.
	9.2	Apply management principles in individual engineering tasks.
	9.3	Contribute to team projects with financial decision-making skills.
	9.4	Apply management principles to teamwork in multidisciplinary settings.
	9.5	Lead projects with sound economic decision-making.
	9.6	Manage multidisciplinary projects effectively as a leader.
Ability to Engage in Ongoing Learning and Professional Development	10.1	Undertake independent and lifelong learning to grow professionally.
	10.2	Adapt to emerging technologies in the engineering field.
	10.3	Develop critical thinking to navigate technological change.

DISCUSSION

To ensure that the 35 descriptors aligned with all the EA stage 1 competencies and indicators of attainment, the newly derived framework was compared. All indicators of attainment were mapped at least once, with some mapping to multiple. This demonstrates that this framework would allow for the EA competencies to be covered by this framework. This was the first validation method. The CDIO knowledge library was the second professional framework that was used to validate the mapping process. Both the CDIO syllabus 3.0 and CDIO standards 3.0 were assessed for alignment with the new framework. This syllabus allows for the ABET criteria to be assessed for alignment as the CDIO syllabus complements and expands on it. Syllabus 3.0 was developed with direct updates to reflect the professional sustainability, digital literacy skills. contemporary societal changes and lifelong learning. These cross the professional skills framework developed within four out of five of the building blocks of the CDIO framework. The CDIO standards also aligns with the newly developed framework by comparing the rationale and the 35 sub-skill descriptors. All 35 sub-skills descriptors we aligned to the 12 CDIO standards.

To further validate the framework against graduate frameworks and professional standards, the framework was compared and mapped against the EA code of ethics. This document standardises the minimum required ethical practice of engineers in Australia. This document is typically not taken into consideration when discussing professional skills however, the

authors argue that the limited scope in which most competencies detail ethics is too shallow and does not set students up for success. The EA code of ethics has four governing sections that is further broken down, and then more granulised again. The four main themes are demonstrate integrity, practice competently, exercise leadership and promote sustainability.

The mapping process was conducted through a systematic analysis of each section and sub-part of the EA Code of Ethics. This involved interpreting the ethical principles and aligning them with relevant competencies within the framework, focusing on problem solving, professional, and interpersonal dimensions. This approach provided a comprehensive understanding of the framework's alignment with ethical engineering practices while identifying specific areas for enhancement to ensure a more holistic integration of the EA Code of Ethics. The mapping demonstrates alignment across all four themes, reflecting a focus on integrity, competence, leadership, and sustainability. Nonetheless, several gaps were identified. These include limited emphasis on stakeholder engagement, structured ethical decision-making, and the use of advanced digital tools for sustainability and safety assessments. Areas such as dispute resolution, and conflict management could be further emphasised. As such, stakeholder engagement, dispute and conflict management and resolution will be further added to the framework explicitly.

Feedback literacy is described by Carless and Boud (2018) as “the understanding, capacity and dispositions needed to make sense of feedback and use it to enhance one’s work and learning”. Being feedback literate as an engineer is an important skill to make judgment of information and make improvements. The current framework includes 7.1 “Receiving and providing constructive feedback”, however, it fails to acknowledge the importance of evaluative judgment and actioning feedback. Self-Agency, also known as having personal agency or agentic behaviour, refers to a persons capacity to act proactively and independently, make choices, and drive personal or professional development. Self-agency is particularly important as it promotes individuals to identify and solve problems independently or by engaging others, which significantly contributes to their projects, teams, and/or organisations. Students are required to consistently develop their self-agency to succeed in their coursework, although stakes are much lower than in a professional setting as the tasks often come with detailed description and guidance. Neither feedback literacy or self-agency are competencies that are well represented in the professional engineering skills framework, nor explicitly presented in EA and WA. While not explicitly mentioned in any of the frameworks, the characteristics are somewhat implied within various skill descriptors, however, do not fully paint the picture. Better integration of feedback literacy and self-agency can create a powerful framework for professional skills development. Pairing the two, individuals not only understand and apply feedback but also take proactive steps to drive their own growth. There is an opportunity perform a systematic analysis of the existing competencies and alignment with the principles of self-agency and feedback literacy to identify gaps. This approach would provide a comprehensive understanding of the framework's strengths and areas for enhancement, ensuring that graduates are equipped with the necessary skills to enter the workforce.

One specific sub-skill descriptor that is currently undergoing a revision to determine if it requires more specific wording is the use of engineering tools due to the current landscape of higher education and industry with the uptake of GenAI. Identified in previous work (Quince & Nikolic, 2024; Quince et al., 2024; Quince et al., 2024) noted that students are not aware of some of the ethical factors and use of the technology. They also demonstrated by a systematic literature review that there was little research undertaken about ethical implementation in engineering education and practice. As such, the framework may need to adapt to 1. Specifically list GenAI in the tools competencies, 2. List GenAI in several sections, or 3. Is

there an overarching assumption that GenAI is implied in all the competencies? Given the fast-paced nature of technological advancements, the authors believe that it is critical that stakeholder perspectives are audited at this critical juncture in the implementation.

Future Framework Implementation

To further validate the framework and ensure that there is alignment with the works aims, the framework was implemented into a survey that will be used in the overarching project. The preliminary survey was distributed to students an academics for validation and feedback using the professional engineering skills described in Table 4 to determine if there were any misunderstandings with the phrasing or if any skills were missing.

Participants were asked to rate the importance of professional skills using the ten main descriptors first and then rating the sub-descriptors, each set also included an open-ended question where participants were asked to provide a reason for the rating. Descriptor 9. Ability to Apply Project Management Skills was one of the lowest rated professional skills, although averaged to be rated as important. When reviewing the sub-descriptors these were considered to be less important than the generalised overhauling skill descriptor. The open-ended question suggest that most participants considered the sub-descriptors to be related to manager roles, suggest that these may need some further examples to contextualise their meaning before launching the survey for wider response. Alternatively, as in the case of 7.3 Lead teams effectively, which was rated of lower importance, it may be worth considering whether there is a misalignment in the expectations for graduate engineers to take on a leadership role. Instead, it might be more relevant to consider the ability to work as part of a team and self-agency instead. This is something that can be further explored once data has been collected and triangulated across students, academics and industry.

The framework will first be utilised to create a detailed database of the professional engineering skills that are both used and important as a graduate engineer. This will be undertaken by mapping the 86 activities that were used in the first BeLongEng survey. “The BeLongEng Project is tracking the practices and contexts of a cohort (panel) of individual engineers over time, using a prospective longitudinal cohort approach. It is anticipated that this project will provide evidence into how and why engineering practice is changing, leading to a more responsive and productive learning and workplace ecosystem.”. This will allow the authors to generate a list of the important sub-skill descriptions and the most used. By generating these lists, a very detailed snapshot of the current industry use of these skills can be compared to students and academics.

To gather the perspectives of students perceptions to their professional skills development throughout their degree and preparedness to enter the workforce, and both students and academics views on importance a survey will be used. The described framework and survey will be provided to students and academics in the first half of 2025. Four institutions are currently part of the study including a New Zealand university. It is expected that this work, along with the application of the framework to the activities that participants have responded to through the BeLongEng Survey will help inform the current engineering education practice across the country to align and continue the redevelopment of the methods professional engineering skills are taught.

CONCLUSIONS

The proposed COMPASS framework, based on the Washington Accord and tailored to the Australian and New Zealand engineering education landscape, addresses the identified gaps in current curricula. The incorporation of more accessible language and greater granularity in

the description of professional engineering skill is essential to enhance understanding among stakeholders. This study signifies the need for continuous evaluation and adaptation of engineering education to meet evolving industry demands. Future research should focus on validating the framework through empirical studies and exploring its implementation across diverse educational settings.

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DESIGNING FOR DIVERSITY: SOFT LANDINGS AND DEVELOPMENTAL PORTFOLIOS IN AEROSPACE EDUCATION

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ABSTRACT

Coordinating and executing an MSc program is accompanied by various challenges. To name a few: a) students joining the program means have diverse backgrounds which means varying levels of prior knowledge, and b) in a program that offers specialization into different profiles, it is important to ensure that every student attains the required breadth in foundation as well, which the program mandates. At the Aerospace Structures and Materials (ASM) Department in the Faculty of Aerospace Engineering at TU Delft, we are developing a core curriculum that encompasses the first education quarter (8 weeks, 15 ECTS), which aims to successfully tackle these challenges in order to train up future aerospace engineers with solid technical foundation, critical thinking ability and collaborative working spirit. The module starts with a "soft-landing" for the students and is followed by three content sprints that cover the essentials in the three principal domains of ASM – Materials, Manufacturing and Modelling. Engineering and consulting assignments have been embedded that tie the sprints together and offer inspiration and motivation for the students. In parallel, students get trained in transversal skills. A student facing dashboard will provide comprehensive feedback on learning progress and outcome. The dashboard will additionally support the transition towards a portfolio-based assessment. In this paper, we outline key features of the core curriculum along with the process that was employed for its development.

KEYWORDS

Curriculum Development, Portfolio assessment, Standards 4, 7,11, Optional Standard 1

INTRODUCTION

A common challenge in master's programs is integrating students from varied academic and professional backgrounds while ensuring they achieve an even foundational understanding essential for advanced specialization. For instance, in the year 2024/2025, at the TU Delft master specialization on Aerospace Structures and Materials (ASM), 44% of the students had done the bachelor in our faculty (See Figure 20).

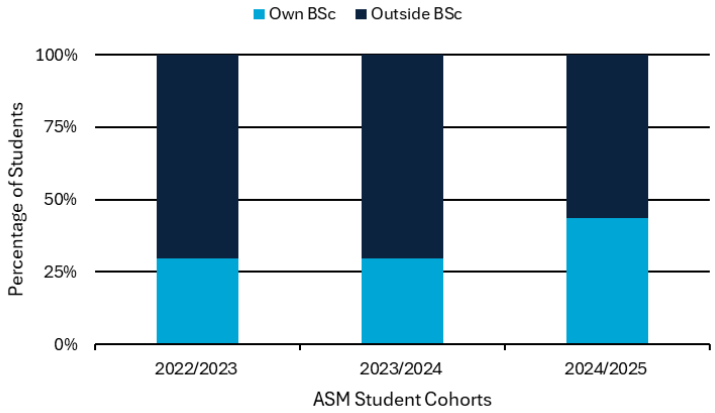


Figure 20 Percentage of MSc students with a background in the TU Delft Aerospace Engineering bachelor's program, by cohort

When restructuring the core module of the Aerospace Structures and Materials (ASM) master, the department decided to tackle these challenges. The new core module of the master would aim to cultivate “T-shaped engineers” by equipping students with a comprehensive understanding of the three key domains: Materials, Manufacturing, and Modelling, while also preparing them for success in their specific areas of expertise. To reach this goal, the core module was developed collaboratively through intensive workshops by multiple staff members. The development of the core module is aligned with the principles of the CDIO (Conceive-Design-Implement-Operate) framework (Malmqvist et al., 2020).

The core starts with a "soft-landing" phase, where the module first addresses knowledge gaps and familiarizes students with the expectations of the master's program. This is directly connected to the CDIO Standard 4: Introduction to Engineering. The “soft-landing” phase prepares students for the demands of engineering practice, giving them space and time to repair any content deficits at their own pace.

Then, three content sprints on Materials, Manufacturing, and Modeling follow the intro phase. Two aerospace specific projects combining transversal abilities with topic knowledge weave the sprints together. These assignments are guided and performed in teams. In this way, disciplinary knowledge is integrated with interpersonal skills development, promoting holistic learning as recommended by the CDIO Standard 7: Integrated Learning Experiences. Moreover, students engage in dedicated learning experiences throughout the sprints to build the skills needed to contribute to sustainable innovation in aerospace engineering. This aligns with Optional Standard 1 (Sustainable Development).

A key feature of the module is the introduction of a student facing dashboard, which provides real-time feedback on learning progress and supports the transition to a portfolio-based assessment system, in line with CDIO Standard 11 (Learning assessment). This system places the responsibility on students to demonstrate their achievement of the learning

objectives, serving as an integrated tool to align what is taught with what is learned (Cain et al., 2018).

This paper offers an overview of the ASM core module's design, highlighting its pedagogical innovations and the process behind its development. By addressing the diverse needs of incoming students and drawing on established educational frameworks, the core module aims to enhance the learning experience and better prepare students for advanced studies in aerospace engineering.

CORE SETUP

The ASM core is being designed to take place as a full-time study load over an eight-week period at the beginning of the academic year (see Figure 21). It will consist of several content-related 2-week sprints (content sprints) that cover key disciplinary knowledge needed by all students in the ASM track. To tie these sprints together and provide an engineering context for applying the knowledge, a pair of projects from an engineering design and consulting perspective will take place over the entire eight-week core. In addition to the main content sprints, elements related to digital skills and sustainability will be interwoven with the projects and reinforced over the entire eight-week core. Finally, to kick off the core and provide a soft-landing to incoming students, a two-week introduction & repair sprint is being designed. Further details of each of these elements will be elaborated on in the remainder of this section.

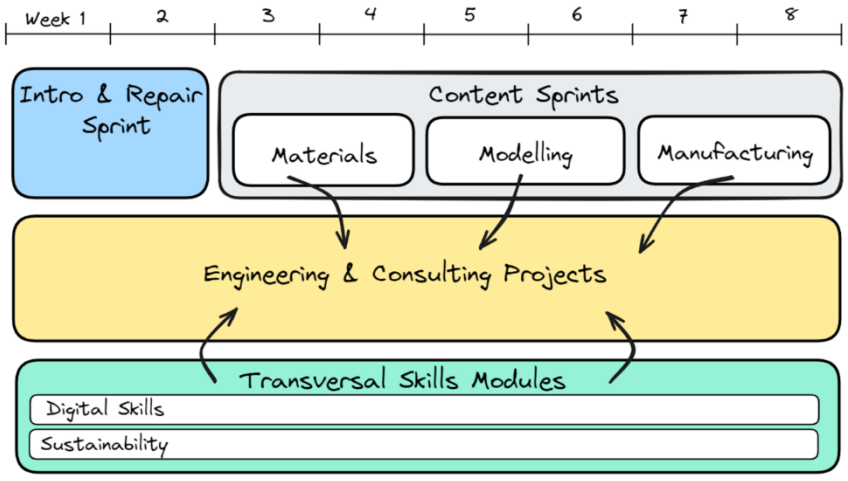


Figure 21: Concept map for the ASM core redesign

Engineering & Consulting Projects – A Common Context for Learning

The backbone of the new ASM core will be two aerospace assignments that interconnect and engage students with the content taught within the content sprints and transversal skills modules. The assignments will run in parallel throughout the whole core module. For instance, as seen in Figure 24, the student teams will have to work simultaneously on both projects during the manufacturing sprint.



Figure 22. Artist concept of projects during the Manufacturing Sprint

The first assignment, called the *Engineering Project,* has the aim of providing an open but scaffolded design project in which the student groups can apply the knowledge gained during the different sprints. The teams will have to identify critical material properties, use these properties to develop structural models to analyze and design the structure, and develop a manufacturing and production plan to realize their designs. The intent is for this project to be hands-on and permit failures and struggles without hampering the overall learning process.

The *Consulting Project* serves as a counterbalance to the *Engineering Project*. In the *Consulting Project*, students will have to review and evaluate work that has been done by a fictional company. Through critically analyzing data and models they will try to understand the material, modelling, and manufacturing choices that were made. In this way, the tasks here will focus on higher-level critical thinking and evaluation, and they will allow the staff to confront students with common errors and misconceptions that students often make.

Both projects are embedded in the aerospace context: The *Engineering Project* will be centered around the design of a liquid hydrogen storage tank for an aircraft, while the *Consulting Project* will be focused on an organic truss-like structure made with additively manufactured metals, such as the one found in the landing gear of a reusable rocket.

Introduction & Repair Sprint – Setting Students up for Success

The essence of learning is that it involves teaching learners to apply cognitive structures they have already developed. Because learners cannot learn to apply cognitive structures they do not yet possess, the basic cognitive architecture must first evolve on its own. Learning experiences that are designed to teach concepts that are clearly beyond the current stage of cognitive development are a waste of time for both teacher and learner. Designed to provide arriving students a "soft landing," the introduction & repair sprint is the first of our two-week sprints.

This sprint gives students the time and space to adjust to our department's particular instructional approach and to fill in any knowledge gaps. Establishing a basis of knowledge and abilities necessary for success on the ASM track is the main goal of this sprint.

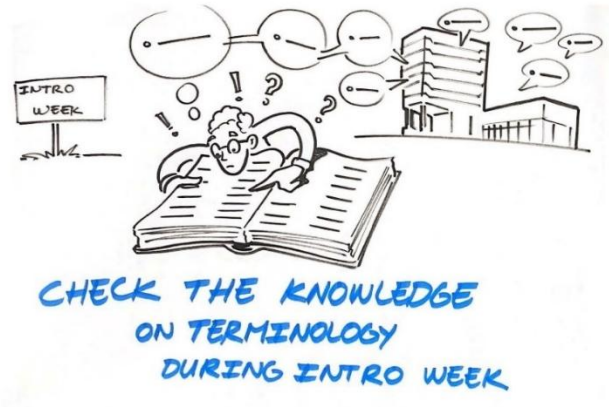


Figure 23. Artist concept of the Intro Sprint

A challenge of doing this well is that each student has different strong and weak areas. For instance, on a discipline level, a student with a materials background might struggle with the aerospace terminology (see Figure 23. Artist concept of the Intro Sprint). On a digital skills level, students from different programs might be used to different programming languages and/or software and may need support in that area. On the interpersonal skills, students from different cultural backgrounds may not be used to the expected independence and collaborative environment and will need time and mentorship to be able to adjust.

The Intro Sprint activities will include a formative entry test to identify content deficiencies, which will be followed by personalized feedback and online materials that can be followed to repair the identified weaknesses. During this sprint, the students will be introduced to the structure of the core and working teams will be formed. The goal would be to balance each team with different academic and cultural backgrounds so the individuals can learn from each other. Finally, the students will be introduced to the research done in the department through standalone lectures which will serve as a motivational tool for the rest of their master.

Content Sprints

The content sprints replace the three core discipline courses covered in the previous course design. Topics have been consolidated into the domains of material science, modelling & structural analysis, and manufacturing, resulting in the three content sprints of the same disciplines. What is unique about the new setup is that students focus on one domain over a condensed period of time and explore it through a combination of teaching activities interwoven with the engineering and consulting projects previously mentioned. How this is done for one of the sprints – the material sprint – will be used as an example of how this is done for all of the sprints.

The materials sprint immerses students in the study of aerospace materials, encompassing the fundamental understanding and application of metals, polymers, ceramics, and composites. It is built on the materials engineering philosophy tailored specifically in the context of aerospace materials.

The curriculum emphasizes a pedagogical blend that integrates teacher-led theory instruction, hands on experimentation and collaborative classroom experiences, and self-directed student exploration. In the first week, lectures establish the foundational knowledge of diverse materials to be employed in aerospace systems, highlighting their mechanical/thermal/physical/chemical properties, processing/manufacturing techniques and limitations in the context of *Engineering Project*. By the end of the first week of the sprint,

students will be able to grasp and design their own Ashby-type plots regarding aerospace materials. Case studies presented in lectures, such as short historical analyses of aerospace failures (e.g., the Space Shuttle Challenger and Columbia), encourage students to connect material science principles with practical engineering decisions and safety considerations. So the students would Understand the importance and strategic impact of research and technological development on society

Active learning is central to the sprint, in the second week, students are offered lab session opportunities to directly engage with materials in *Consulting Project*. Hands-on lab activities such as mechanical test of metals, microscopy analysis of metal and thermal expansion calculation of given metal part will set an important base on analyzing some key material features. Such activities enable students to observe material behavior and compare the results to supplied technical report, reinforcing critical thinking by experimental understanding.

To enhance self-directed learning, the sprint incorporates student-paced activities, such as independent research on emerging aerospace related materials in groups. Group projects are integral, fostering collaboration and teamwork as students design, evaluate, and present material solutions for specific aerospace challenges, such as sustainable composites, corrosion resistant coatings or ultra-high temperature ceramics for thermal protection system applications. These activities allow students to explore specialized topics at their own pace, promoting critical thinking, innovation, the ability to integrate multidisciplinary knowledge and share their findings in a concise way.

Transversal Skills Modules

To complement the knowledge centered content sprints, the core is also designed to have two skills-based modules – Sustainability and Digital Skills - that run throughout the entire core module. Currently, the sustainability module is further along in its design. It begins by introducing students to the complexity of the current climate crisis by engaging students in the interactive Climate Fresk workshop (Widmann, 2024), promotes discussion and discourse on sustainability related topics through organized debates, and concludes with an introduction to the more engineering approach of Life Cycle Analysis for quantifying sustainability in an engineering design and decision-making process. The digital skills module is not currently well defined but is expected to be centered around analyzing and organizing data and the FAIR principals for data management (see Figure 24).



Figure 24: Artist concept for the Digital Skills module

DEVELOPMENT PROCESS

The core module was developed collaboratively through intensive workshops by multiple staff members (592 man-hours throughout a period of 14 months) based on the **D**elft **A**pproach for (**R**e)designing **E**ducation design methodology. Inspired by the Carpe Diem methodology and Gilly Salmon (Salmon, 2023) for (re)designing, developing, implementing and evaluating (blended) subjects within higher education, DARE was developed by the blended team of Teaching and Learnings Services of the TU Delft. It has the following underlying principles: constructive alignment, backward design, team based and modular.

It consists of 8 steps that allow an educational advisor to guide teaching teams in a structured way through the entire design process. In March 2023, a week-long workshop was implemented for the team (8 people) to give aspirations of the course such as what they want to achieve through core, combined with the course analysis. This is called the *blueprint* step. During the course analysis, constructive alignment between learning objectives, learning activities and assessment is particularly scrutinized in this step. From April to May in 2024, more staff members were gathered in 4 different full day workshops to move on from the blueprint to the desired evidences and finally the instructions and materials. This is the storyboarding step. With the desired outcomes in mind from the blueprint step, the storyboard is a visual representation of the subject design. In this step, the constructive alignment, backward design and the blend of learning activities are most visible.

During the story boarding step, we also made the innovation by having an artist on board during the workshops who visually created drawings as he was eavesdropping the discussions in the room. This way, a representation of the concepts the teachers try to communicate through words could be visualized in a more intuitive and concrete way, e.g., Figures 3-5 are examples of artistic representation of proposed concepts. The storyboard is the basis of the subject design and is further elaborated during the prototype phase. During the prototype phase, the course team creates prototypes of the learning activities. Using a template, they write the first outlines of the learning activities. This helps to get a more concrete picture of what the course will look like. This is where we are right now.

FEEDBACK AND ASSESSMENT

Feedback via an interactive dashboard

For the core module, the idea to develop a framework as a Learning Analytics Dashboard to supplement traditional grades with quantitative visualizations, showcasing student understanding across various topical areas, their affinity towards different skills, and their disposition towards assessment types. This will enable feedback and assessment over the breadth of the module.

By providing such a comprehensive snapshot of the learning process and progress, this approach aims to empower both the teachers and students. Teachers gain deeper insights to identify blind spots, while students gain the self-awareness necessary for effective learning strategies. An illustration of the student dashboard is shown in Figure 25.

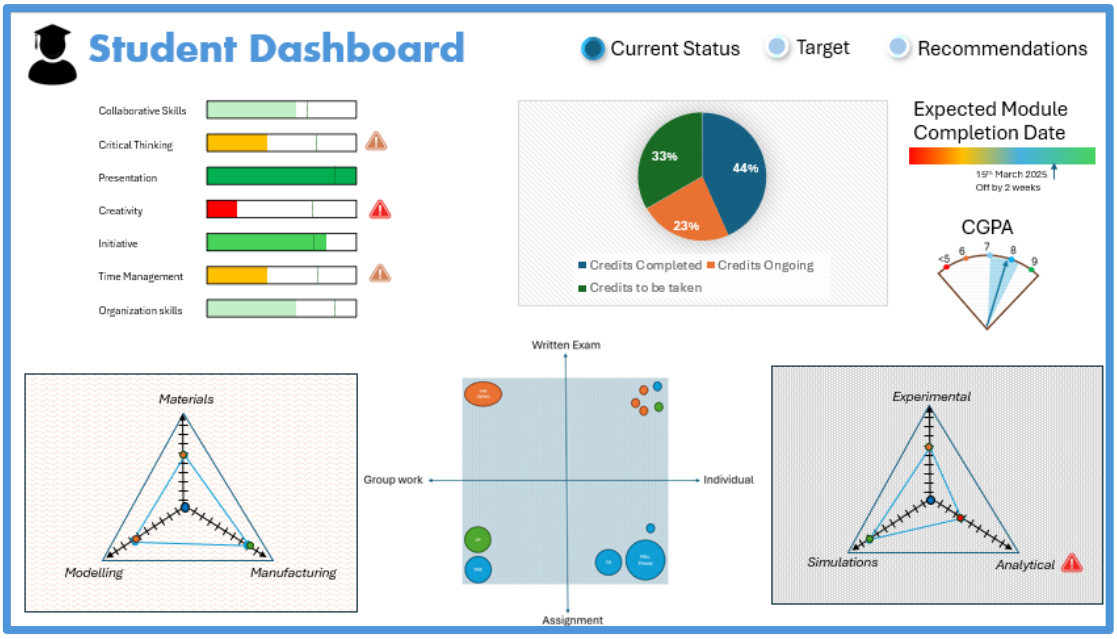


Figure 25. Illustration of a sample student dashboard.

Digital Learning Environments provide a convenient platform to record scores and grades on multiple criteria over time, and also seamlessly capture student interactions and activity. These interactions have the potential to add valuable insight to learning strategies and can form the base for actionable feedback to learners. It has been shown that awareness of learners about the learning process increases through visualizations. Sense-making is drastically improved by meaningful presentation of information. It is important to ensure that Dashboards are not just student-facing but also student focused, providing awareness, reflection, prediction and recommendation (Kuosa, 2016).

The aim is to develop a Dashboard designed to assist learners in managing their study plans, tracking goals, and monitoring progress. The dashboard will provide a detailed breakdown of progress, moving beyond simple grades to offer insights into affinity, knowledge areas, and disposition. It will also evaluate learners' development in transversal skills and provide predictive analytics and personalized recommendations. Additionally, the platform will facilitate peer comparison and help identify knowledge gaps and missing prerequisites, offering a comprehensive tool to enhance the learning experience.

The dashboard will also support staff with curriculum portfolio and course management. This can be also used to extract effectiveness in different teaching methods.

Assessment: Moving from grades to Portfolio

One of the requirement of the dashboard design is to facilitate portfolio-based assessments of the module. Such a portfolio can be used to demonstrate learning achievement for assessment purposes (Assessing by Portfolio, 2025). Moreover, a student portfolio offers many advantages with respect to self-regulated learning – registering performance, reflection on learning, setting up study plans, archive of experience and more (Cain, 2018).

The portfolio approach also addresses broader challenges in assessment practices. By enabling continuous feedback and progress tracking, it ensures alignment with intended learning objectives, as highlighted by Kovacs et al. (Kovacs et al., 2023). Additionally, moving away from traditional grades to a portfolio system acknowledges the findings of Willems et al.

(Willems et al., 2024), who noted that grades can either encourage or hinder students' willingness to innovate. By focusing on developmental feedback and reflective learning, the module fosters an environment where students are motivated to explore, experiment, and innovate.

The digital dashboard eases the process of data archiving and makes the maintenance of a student portfolio less tedious. Challenges with respect to mandated vs voluntary use, scaling module portfolio to program and job search, assessment consistency and cross faculty buy-in need to be addressed.

CONCLUSION

The core curriculum redesign in the department of Aerospace structures and Materials at TU Delft has been a departmental effort aiming at providing the next generation aerospace engineers with more customized and empowered learning experiences. The curriculum was designed to enable soft-landing upon boarding to tailored feedback dashboard, and eventually to the final certification at the end of the core module. Group teaching and group learning are promoted to foster collaborative environment with a focus on fundamental concepts that are necessary for the program while keeping the aerospace context. As we continue to venture into this redesign, we are on the way of prototyping and creating course material content, while continuing to seek insights and suggestions on portfolio management and assessment control.

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Mahsa Sajedi is an educational advisor and curriculum designer at Delft University of Technology. In 2017, she was awarded the Teach For Australia scholarship through which she completed her Master in Education, while working as a teacher. Her experience includes working in Australian universities and bridging programs and high schools. She is passionate about designing programs that work well for students and teachers, applying educational sciences and evince-based practices, and bringing educators together to work in interdisciplinary ways of teaching and assessing.

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EXAMINING ARCHITECTURAL DESIGN PROJECTS THROUGH CDIO: PREPAREDNESS, TASK DESIGN, FEEDBACK, AND COLLABORATION

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ABSTRACT

This study explores the dynamic interplay of preparedness, task design, feedback, and collaboration in shaping student engagement and performance in architectural education, framed within the Conceive-Design-Implement-Operate (CDIO) standards. By integrating qualitative and quantitative methodologies, the research investigates how these factors influence the learning experiences of architecture students during two distinct design projects: a complex urban resort and a simpler ferry terminal. Coding and thematic analysis was employed to analyze focus group discussions, while statistical analyses validated relationships among key metrics such as enjoyment, effort, control, and openness. The findings reveal that academic preparedness plays a foundational role in equipping students to navigate the demands of architectural design courses, with prior technical exposure being a critical enabler. Task design emerged as a significant motivator, with structured and phased assignments promoting incremental progress and sustained engagement. Feedback was identified as a catalyst for growth, emphasizing the importance of clear, constructive, and timely communication in cultivating student confidence and skill development. Collaboration, while enriching peer learning and creativity, posed challenges related to group dynamics and equitable contributions. These insights align with CDIO Standards 2 (learning outcomes), 3 (integrated curriculum), 5 (design-implement experiences), and 7 (integrated learning environments), underscoring the value of interdisciplinary and practical approaches to architectural education. The study also highlights the importance of openness to feedback and new ideas as a driver of student engagement and performance.

KEYWORDS

Architectural education, Student engagement, Feedback mechanisms, Task design, Collaboration, Standards: 2, 3, 5, 7

INTRODUCTION

Architectural education must balance technical proficiency, creativity, and collaboration to prepare students for the complexities of professional practice. Integrating technical and practical knowledge into design tasks is crucial, as demonstrated by programs like the University of Hartford's approach, which blends academic-based theoretical studies with industry-focused problem-solving to enhance career readiness (Petry, 2004). Hands-on activities, such as design-build programs, further reinforce students' understanding of architectural phenomena by providing real-world contexts for learning (Amer, 2015). Effective task design, incorporating collaborative projects, plays a vital role in developing teamwork and problem-solving skills essential for architectural practice. Collaborative design studios and multidisciplinary approaches, such as those outlined in Multiple Criteria Decision Support frameworks, foster interdisciplinary collaboration and improve design outcomes (Emam et al., 2019; Kamaraj et al., 2025).

Feedback mechanisms also significantly influence learning outcomes by providing students with opportunities to assess their progress and refine their skills. Interactive tools such as peer assessments and structured time-task schedules offer constructive feedback while maintaining engagement (Emam et al., 2019). Emerging technologies, such as Extended Reality (XR), further enhance these mechanisms by offering immersive and interactive learning environments that bridge theoretical concepts and practical applications (Crolla et al., 2024). Collaboration, a cornerstone of architectural education, encourages creativity and problem-solving but requires addressing common barriers like coordination challenges and conflicts. Collaborative projects and targeted training in teamwork skills are essential for encouraging effective partnerships (Karimi & Farivarsadri, 2024). To comprehensively evaluate the impact of these pedagogical strategies, mixed-methods approaches that combine qualitative observations with quantitative data, such as thematic analysis and structured questionnaires, provide valuable insights into teaching efficacy and areas for improvement (Ramadhan et al., 2024).

The core of architectural education in the Philippines is the Architectural Design courses that are offered from freshmen year to senior year. In the School of Architecture, Industrial Design, and the Built Environment of Mapua University, the architecture program offers Architectural Design 1 to Architectural Design 12. At the heart of its program of study is the design process. The design process is a method in formulating an architectural design solution. Concept development is generated through this method by the learners in order to articulate their design. Thus, from an architecture perspective, the study aims to investigate how the design process is being utilized by the design students, and it is hypothesized that it encourages and fosters creativity in students.

The Conceive-Design-Implement-Operate (CDIO) framework (Crawley et al., 2014), originally developed for engineering education, offers significant potential for transforming architectural education. By emphasizing hands-on learning, team collaboration, and practical applications, CDIO aligns with the core principles of architectural education (Nyka et al., 2020). Institutions like Gdansk University of Technology and Singapore Polytechnic have successfully integrated the CDIO framework into their curricula, focusing on experiential learning and sustainability (Ho & Leong, 2023). For example, Gdansk University has demonstrated the benefits of "research by design," enhancing practical and research skills. Similarly, Singapore Polytechnic has mapped their programs to CDIO standards and progressively incorporated sustainability knowledge over three years. Challenges, such as adapting to cultural differences in educational systems, highlight the need for flexible implementation strategies, especially in diverse settings like China (Cui & Wang, 2014). Despite these challenges, the CDIO approach

promotes continuous improvement, requiring regular curriculum evaluation to meet evolving industry standards and educational goals. Architectural education inherently requires the integration of technical skills, creativity, and collaboration, aligning seamlessly with CDIO's emphasis on hands-on, project-based learning. By adopting CDIO standards 3.0 (Malmqvist et al., 2022), such as comprehensive learning outcomes (Standard 2), integrated curricula (Standard 3), real-world design-implement experiences (Standard 5), and collaborative feedback mechanisms (Standard 7), architectural programs can provide a structured yet flexible framework that bridges academic learning with professional practice.

This paper offers insights for educators on optimizing tasks, enhancing feedback, and fostering collaboration, presenting a model to understand contextual and individual influences on architectural learning for future pedagogical strategies.

METHOD

The study employed a mixed-methodology approach, utilizing an online design process tool that also incorporated subjective assessments. A focused group discussion was conducted to gather insights and reflections from the students and the design professor regarding the locus of control and self-efficacy measures. This study employs a thematic analysis, integrating quantitative measures and demographic data, to provide a mixed-methods perspective.

Qualitative Analysis

Coding and thematic analysis as qualitative research method used to identify recurring themes, patterns, and concepts in textual data in focus group discussions by tagging data segments (codes), grouping them into categories, and extracting supporting quotes. This method reveals patterns in experiences, preferences, or behaviors, providing structured, evidence-based findings.

Quantitative Analysis

Quantitative data included self-reported metrics on enjoyment, effort, control, openness, and groupmate ratings collected across two projects. Statistical methods included Pearson correlation analysis to measure relationships, trend analysis to detect changes across projects, ANOVA to test for significant differences, and regression modeling to identify predictors of performance.

Data Sources

Qualitative Data: Focus Group Discussions (FGDs) were transcribed on student discussions. Analyzes extracted themes related to students' experiences in two design projects: the urban resort (complex task) and the ferry terminal (simpler task). The FGDs captured insights into how students approached design tasks, perceived feedback, and collaborated in group settings.

Quantitative Data: Data from an evaluation matrix, including variables such as Hours, Enjoyment, Effort, Openness, Control, and Groupmate collaboration, provided numeric insights into student engagement and task performance.

Analytical Procedures

The analytic procedure of coding and thematic analysis follows a systematic approach to examining qualitative data. Initial immersion in the data through repeated readings establishes familiarity. Meaningful segments are identified and labeled through coding, followed by the organization of these codes into emergent themes that reflect recurring patterns. Thematic refinement occurs through consolidation or subdivision to enhance conceptual clarity. Representative quotations substantiate each theme, ensuring analytic rigor. The process concludes with a presentation of findings through a structured thematic framework that explains key insights from the dataset.

Quantitative Analysis: Statistical correlations between metrics (e.g., Enjoyment, Effort, Control) were computed to validate qualitative observations. Patterns in performance metrics were analyzed for individual students and across projects to detect trends.

Integration of Qualitative and Quantitative Data: Themes emerging from FGDs were compared with quantitative measures to identify convergences and divergences. For example, FGD narratives on feedback quality were supported by variations in Openness and Enjoyment scores.

CDIO Alignment: The analysis is aligned with CDIO Standards 2, 3, 5, and 7. Learning outcomes (Standard 2) guided the identification of preparedness and skill development themes. Task design and its impact on engagement were analyzed concerning integrated curricula (Standard 3) and design-implement experiences (Standard 5). Collaborative dynamics and feedback were examined within integrated learning environments (Standard 7), ensuring the findings align with CDIO's emphasis on interdisciplinary and practical learning approaches.

Projects and Tasks

Students participated in two design projects: (1) Urban Resort, a complex task that required advanced technical and creative skills. (2) Ferry Terminal: A simpler task designed to test foundational skills. Tasks for each project were subdivided into phases, including concept development, drafting, and rendering, to provide a structured learning process.

The study focused on the Architectural Design 6 course offered by the School of Architecture, Industrial Design, and the Built Environment at Mapúa University. This course was chosen because it was available and taught by the researcher during the period of the investigation. Students worked in pairs and were assigned four specific tasks for each project: 1. Concept Development, 2. Site Development Plan, 3. Floor Plans, Elevations and Sections, 4. Poster, and Walk-through. An online questionnaire was administered to the students, who were instructed to respond based on their task. Additionally, they were required to complete the questionnaire at each stage of the design project.

Participants

Participants included undergraduate architectural students from diverse academic backgrounds (e.g., STEM - Science, Technology, Engineering, and Mathematics, ABM - Accountancy, Business, and Management, GAS - General Academic Strand). Their academic preparedness, performance, and engagement were evaluated across both projects. The research participants were composed of 15 male and 15 female students.

RESULTS

Qualitative analysis

This coding and thematic analysis was performed on the transcripts of the two focus group discussions involving architecture students.

Table 1. Summary of thematic coding of the focus group discussion

Theme	Subtheme	Categories	Example Quotations
Preparedness	Academic Alignment	STEM track, ABM track, GAS track	"It was not very connected to design."
	Emotional Readiness	Motivation, Confidence, Anxiety, Fear	"Sometimes when there is an exam and a design project, I feel stressed."
	Demographic Influences	Age, Gender, Experience	"Older ones have more experience because they've gone through what we're going to go through."
Task Design	Task Structure and Clarity	Structured tasks, Unstructured tasks	"Every level seems structured, increasing my enjoyment with each task."
	Project Complexity and Engagement	Complexity (high/low), Creativity, Sequencing	"The complexity of the project really makes a difference in our output."
	External/Internal Factors	External environment, Internal emotional states	"It's comfortable when you're at home because you can focus more; at school, there are distractions."
Feedback	Instructor Interaction	Frequency of consultations, Quality of feedback	"Detailed feedback during consultations significantly improved our work."
	Impact on Performance	Motivation, Technical understanding, Creativity	"The instructor's detailed instructions helped me to better understand what was required."
Collaboration	Team Dynamics	Partner selection, Productivity, Creativity	"It really depends on the partner chosen, but I felt better working individually."
	Peer Influence	Peer-to-peer learning, Influence on design	"With my classmates, I get a lot of ideas and implement them into my work."
	Collaborative Arrangements	Individual vs. paired/group, Benefits, Challenges	"Working in pairs was challenging but beneficial because we could share ideas."

This thematic analysis explains how student engagement and performance in architectural design courses shaped by the interplay of academic preparedness, task design, feedback, and collaborative dynamics, influenced by environmental, demographic, and motivational factors. These elements collectively define the educational experiences of architecture students, emphasizing that no single factor operates in isolation. Instead, their dynamic interaction creates opportunities and challenges for learners and educators alike.

Preparedness as the Foundation

Academic preparedness underpins students' ability to manage the demands of architectural design courses. Students from STEM backgrounds often feel confident in handling technical components, such as CAD and mathematics, which closely align with architectural

coursework. One student noted, "There are some courses...aligned with architecture, like drafting" (Respondent 1 Batch 1). Conversely, non-STEM students from ABM tracks faced difficulties adapting to technical requirements, as expressed: "Not really sir, because of the designing aspect...My course is ABM, so Business" (Respondent 2 Batch 1). Exposure to drafting or CAD during high school helped bridge this gap, highlighting that preparedness involves both academic background and early technical training.

Task Design as a Motivator

Task design has a significant impact on student engagement and learning outcomes. A phased approach to tasks—breaking projects into concept development, floor plans, and rendering—promotes clarity and sustained motivation. A student described, "Every level...seems like I'm having a sense of pressure or enjoying it when I'm doing SketchUp or rendering" (Respondent 7 Batch 1). Conversely, repetitive activities, such as prolonged floor-plan work, led to boredom: "For a week, it was just a floor plan...you get bored" (Respondent 7 Batch 1). Well-structured tasks balance challenge and achievability, maintaining students' interest and enthusiasm.

Feedback as a Catalyst for Growth

Effective feedback is crucial for student growth and engagement. Clear, constructive feedback helps refine students' work and build confidence. One student stated, "The instructions...are detailed...I can interpret them properly and produce what I need" (Respondent 3 Batch 1). In contrast, vague or critical feedback reduces confidence and creativity: "Before there was a professor who was not helpful...our design was being insulted" (Respondent 5 Batch 1). Regular consultations with supportive feedback significantly enhance students' learning experiences.

Collaboration as a Learning Opportunity

Collaboration in architectural education provides peer learning opportunities but presents challenges related to group dynamics. Students valued diverse perspectives and ideas: "Collaboration helped me learn new ideas from my group mate" (Respondent 7 Batch 1). However, unequal contributions caused dissatisfaction: "It seems unfair if your classmate is not attending [consultations] but still gets a good grade" (Respondent 4 Batch 1). Effective collaboration requires compatible group members and fair evaluation systems recognizing individual contributions.

Environmental and Internal Factors Shaping Learning

Workspace conditions and internal emotional states significantly influence productivity and creativity. Many students preferred working at home to minimize distractions and enhance focus: "It’s better to just take the plates home...you are more focused” (Respondent 6 Batch 1). School environments facilitated collaboration but sometimes disrupted individual focus. Internal factors like motivation impacted output quality: “When I’m not motivated...I do a simple, playing safe design” (Respondent 8 Batch 1). Addressing external and internal influences through adaptive strategies is essential.

Demographics and Experience

Demographic factors (age, gender, prior experience) influenced learning dynamics and performance. Older students benefitted from maturity and experience: “Older students have learned something that younger ones haven’t yet” (Respondent 1 Batch 1). Gender differences also emerged, with women recognized for creativity and men for technical skills: “Women are

really good at aesthetics...more creative in imagining and visualizing the design" (Respondent 1 Batch 1). Inclusive practices leveraging diverse strengths are vital in architectural education.

Engagement and Fair Evaluation

Project complexity and evaluation fairness critically impacted academic performance and student satisfaction. Complex projects, such as urban resorts, were more demanding: "The complexity of the project really makes a difference in our output" (Respondent 4 Batch 1). Students emphasized evaluating individual contributions within group projects to ensure fairness: "It is necessary to see if there are improvements after consultations" (Respondent 1 Batch 1). Transparent evaluation methods considering both individual and group efforts are essential for maintaining motivation and trust.

Quantitative analysis

This study investigates the relationships among key educational metrics such as Enjoyment, Effort, Control, Openness, and Groupmate Ratings in the context of project-based learning. Quantitative analysis is used to validate qualitative observations, providing deeper insights into student engagement and performance. By applying statistical methods, this research explores correlations, trends, and predictors of performance, offering recommendations for optimizing learning environments.

Methods

The analyzed data consists of metrics reported at the project level for individual students, including self-reported enjoyment, effort, and control, openness to feedback, groupmate ratings, and hours worked. Statistical methods were applied to achieve the study's objectives. Pearson correlation coefficients were computed to measure linear relationships between variables. Trend analysis calculated mean values for each metric across multiple projects to observe changes over time. Analysis of Variance (ANOVA) was employed to test for significant differences in metrics across projects, while regression modeling was used to identify predictors of key outcomes like enjoyment and effort.

Results

The correlation analysis revealed significant relationships among variables. Enjoyment was strongly correlated with openness ($r=0.55$, $p<0.001$), suggesting that students who are receptive to new ideas and feedback tend to enjoy projects more. Enjoyment also correlated positively with control ($r=0.41$, $p<0.05$) and effort ($r=0.34$, $p<0.05$), indicating that greater perceived autonomy and higher effort levels are associated with enhanced enjoyment. Effort showed a moderate correlation with openness ($r=0.47$, $p<0.01$), highlighting the motivational role of openness in driving engagement. However, hours worked correlated negatively with control ($r=-0.30$, $p<0.05$), indicating that longer working hours are associated with reduced feelings of autonomy.

Trend analysis showed that enjoyment and effort increased significantly across projects, reflecting growing engagement and involvement over time. Control, however, fluctuated, indicating inconsistencies in students' perceived autonomy. Groupmate ratings also improved slightly, suggesting enhanced collaboration with successive projects.

ANOVA results confirmed these trends, with significant increases observed for enjoyment ($F(2,90)=5.67$, $p<0.05$) and effort ($F(2,90)=4.89$, $p<0.05$) across projects. Regression analysis identified openness ($\beta=0.38$, $p<0.001$) as the strongest predictor of enjoyment, followed by

control (β=0.21, p<0.05) and groupmate ratings (β=0.18, p<0.05). Effort was significantly predicted by openness (β=0.31, p<0.01) and project hours (β=0.25, p<0.05).

DISCUSSION

The synthesis of qualitative and quantitative findings provides a comprehensive understanding of the factors that shape student engagement and performance in architectural education. Both analyses emphasize the importance of openness, task design, feedback, and collaboration in creating a supportive learning environment. These interconnected elements demonstrate how educational experiences are shaped by dynamic interactions, highlighting actionable opportunities for improvement. The study's limitations include the relatively small sample size (30 participants), which restricts the generalizability of the findings, particularly in drawing broad conclusions about architectural education across diverse contexts. Then, the study is also highly contextualized, focusing on specific architectural programs, which may limit its applicability to other educational or cultural settings. In light of this, openness emerged as a critical factor in enjoyment and effort, as evidenced in both qualitative and quantitative findings. Students who are receptive to feedback and open to exploring new ideas show greater levels of engagement and motivation. The thematic analysis illustrates how openness enables students to navigate challenges more effectively, while the quantitative analysis identifies it as a strong predictor of enjoyment (β=0.38, p<0.001) and effort (β=0.31, p< 0.01). These findings underscore the need for educators to create activities and reflective exercises that encourage openness, enhancing students' ability to engage with complex tasks.

Task design is also pivotal in sustaining motivation and ensuring productive learning experiences. The qualitative analysis emphasizes the importance of phased, well-structured assignments that provide clarity and facilitate incremental progress, thereby preventing disengagement. Students reported higher satisfaction with tasks that balanced challenge and achievability, as exemplified by the phased design of concept sketches, floor plans, and rendering tasks. Quantitative findings further support this, revealing fluctuating perceptions of control and the negative impact of excessive working hours on autonomy (r=-0.30, p<0.05). Together, these findings underscore the importance of designing manageable and engaging assignments that optimize both effort and outcomes.

Feedback and collaboration are equally significant in shaping learning experiences. Constructive feedback is identified in the thematic analysis as a catalyst for growth, helping students refine their work and build confidence. Students who receive clear and actionable feedback can better meet expectations and develop their skills, whereas vague or overly critical feedback can diminish confidence and creativity. Quantitative results validate this, showing that control (β=0.21, p<0.05) and groupmate ratings (β=0.18, p< 0.05) are significant predictors of enjoyment. These findings highlight the dual importance of feedback and collaboration, indicating that equitable evaluation practices and structured peer interactions can promote improved group dynamics and overall engagement.

Collaboration presents both opportunities and challenges. While group work fosters peer learning and exposure to diverse perspectives, it also introduces difficulties, such as unequal contributions and perceptions of unfairness. Improvements in groupmate ratings over time indicate that collaborative skills can develop progressively when supported by effective team-building strategies and fair assessments. This highlights the importance of structured peer evaluations and transparent grading practices to promote equity and accountability in group settings.

The synthesis highlights the interconnected roles of openness, task design, feedback, and collaboration in shaping student engagement and performance. Educators can enhance learning environments by encouraging openness, effectively managing workloads, and promoting effective group dynamics. The interplay among these factors aligns with CDIO standards 2, 3, 5, and 7.

Particularly, preparedness aligns with CDIO Standard 2 (Learning Outcomes), advocating balanced learning outcomes in technical knowledge, reasoning, and interpersonal skills. This study emphasizes the impact of students' diverse backgrounds on their readiness, suggesting curricula adapt to varied educational needs. Collaboration relates to CDIO Standard 3 (Integrated Curriculum), promoting an interdisciplinary curriculum that supports teamwork and communication skills crucial to architectural education. The findings highlight collaboration's dual role in enhancing learning while posing challenges. Whereas task design corresponds to CDIO Standard 5 (Design-Implement Experiences), it advocates for curricular structures that integrate theoretical and practical learning. The structured task approach described in this study effectively scaffolds learning, maintains student engagement, and supports skill development. Finally, feedback connects to CDIO Standard 7 (Integrated Learning Experiences), emphasizing constructive feedback to refine students' understanding and abilities. This aligns with CDIO's commitment to continuous improvement and adaptive learning.
However, subtle differences exist. CDIO emphasizes hands-on experiential learning more explicitly, directly linking theory to practical applications. This study suggests that further consideration of workspace and environmental influences is warranted, as students expressed a preference for home environments over classroom settings due to fewer distractions and increased focus. Additionally, demographic factors such as academic background, age, and gender, prominent in this research, are less explicitly addressed in the CDIO framework. Furthermore, the study uniquely emphasizes individual contributions within group contexts, highlighting the need for equitable evaluation - a perspective that complements CDIO's broader collaborative approach. Linking these factors to CDIO 3.0 reveals that architectural education benefits from a structured yet adaptable approach, thereby enhancing student engagement and aligning educational practices with professional standards to provide a comprehensive learning experience.

CONCLUSION

This study provides a framework for understanding and enhancing architectural education. Educators can create more engaging and effective learning environments by addressing openness, task design, feedback, and collaboration. These findings contribute to the development of pedagogical strategies that prepare students for the complexities of architectural practice. The integration of qualitative and quantitative analyses provides a comprehensive understanding of the factors influencing student engagement and performance in architectural education. Openness emerged as a critical driver of engagement and motivation. Students who are receptive to feedback and new ideas perform better and experience higher levels of enjoyment and effort. Task design was another significant factor, with phased and well-structured assignments enhancing clarity and maintaining motivation. On the other hand, poorly designed tasks led to disengagement and diminished autonomy, underscoring the need for a balance between complexity and achievability. Feedback and collaboration were found to be critical in promoting growth and enhancing learning experiences. Clear and constructive feedback helps students refine their work and build confidence, while effective collaboration promotes peer learning and supports the

development of critical teamwork skills. However, challenges such as unequal contributions in group projects highlight the need for transparent and equitable evaluation practices.

The findings highlight the importance of creating an inclusive and engaging learning environment that supports the diverse needs of students. Educators should focus on openness, designing manageable yet challenging tasks, providing constructive feedback, and facilitating equitable collaboration. Addressing these factors holistically can enhance individual and group performance, ensuring a more productive and rewarding educational experience.

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BIOGRAPHICAL INFORMATION

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ASSESSING SUSTAINABILITY IN KUWAIT'S HIGHER EDUCATION INSTITUTIONS' ENGINEERING CURRICULA

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ABSTRACT

As engineering is a discipline that is the center of most of the United Nations Sustainable Development Goals, engineering higher education institutions must play a significant role in promoting sustainable livelihoods. This paper aims at assessing the inclusion of sustainability concepts in Kuwait's higher education engineering curricula. It presents the results of a sustainability survey which evaluates the current state of sustainability education in engineering higher education institutions; faculty members' experiences in integrating sustainability principles into their courses; and faculty members' views on the importance of sustainability in engineering curricula. The survey results show that sustainability concepts are mainly introduced as portions of fundamental courses such as introduction to engineering, graduation projects, research projects, or through extra-curricular activities such as conferences, seminars, and workshops while a clear framework governing the delivery and assessment of such concepts at the program level is still not well established.

KEYWORDS

Engineering, education, sustainability, sustainable development goals, CDIO standards: 1-3, 5, 11-12.

INTRODUCTION

The unprecedented demand for natural resources in the last century had resulted in an adverse impact on the environment, societies, and economies around the globe. The United Nations (UN) General Assembly adopted 17 Sustainable Development Goals (SDGs) in September 2015 to promote sustainable development across the Globe (United Nations, 2015). This was a very ambitious effort to place goal setting at the center of global policy and governance to drive sustainability (Biermann et al., 2017; Kanie et al., 2017).

Governments and industries across the world have since used the UN SDGs as a basis for various policies, procedures, and practices, making it imperative that the future work force is aware of the sustainable practices to drive the future development agenda. Kuwait's 2035 vision adapts the UN SGDs 2030 agenda to the unique Kuwaiti economic, social, and environmental conditions to transform Kuwait into a financial and trade hub regionally and internationally and becoming more attractive to investors (General Secretariat of the Supreme Council for Planning and Development of Kuwait, 2020). The pillars of the National Development Plan (2035 Vision) are: sustainable diversified economy; effective civil service; sustainable living environment; developed infrastructure; high quality healthcare; creative human capital; and global positioning (Ministry of Foreign Affairs, State of Kuwait, n.d.).

As governments and industries across the world reconfigure their development strategies to align with UN SDGs, it is imperative that the future work force is aware of the sustainable practices to drive the future development agenda. Hence, education at all levels needs to play a significant role in promoting sustainable livelihoods. (Quelhas et al., 2019) defines education for sustainable development as the education that aims at preparing individuals to deal with economic, social, and environmental problems that threaten sustainability. This education needs to go beyond the knowledge and understanding of environmental and social issues, to affect attitudes, change behaviors, and promote competencies needed to shape a sustainable future (UNESCO Representation in Brazil, 2017). To drive real change, the students need to go beyond increased awareness of sustainable practices and change their attitudes and behaviors to support sustainable practices.

Studies conducted at the beginning of the new millennia suggested that engineering students' knowledge of sustainability practices was not satisfactory with significant knowledge gaps in various areas. Since then, studies were conducted to promote education for sustainable development. Rose et al. (2015) stated that students' awareness of sustainable practices was improved by embedding sustainability into a first-year engineering curriculum through a deliberative and dynamic renewal process that brought together internal and external stakeholders through a structured sequence of facilitated workshops and meetings. Various curriculum renewal processes around the world have achieved similar outcomes with respect to increasing students' awareness of sustainability practices (Bjornberg & Skogh, 2015; Byrne et al., 2013; Colombo & Alves, 2017).

The Conceive, Design, Implement, and Operate (CDIO) community also played a key role in innovating novel approaches to incorporate sustainability into higher education curricula, Miñano-Rubio et at. (2016) provided a comprehensive methodology to integrate sustainability in CDIO projects. Malmqvist et al. (2019) discussed development ideas for the CDIO standards and suggested optional standards, one of them is related to sustainability. Cheah et al. (2022) discussed how to best deliver education for sustainable development for transformational learning.

In alignment with the international UN objectives for education for sustainable development (UNESCO Representation in Brazil, 2017) as well as the requirements of the country-specific vision (New Kuwait 2035), and as a first step towards the development of pedagogical strategies in Kuwait's engineering higher education institutions to graduate engineers who are assets for the achievement of the worldwide sustainable development goals, this paper investigates the inclusion of sustainability concepts in Kuwait's higher education engineering curricula. Whereas its first part presents the survey questionnaire and methodology used to collect data, its second part provides the survey results, and its last part discusses the major outcomes and conclusions drawn from the data analysis. This is aligned with CDIO standard 12 which highlights the importance of reviewing engineering programs to take decisions about a program and its plans for continuous improvement.

SURVEY QUESTIONNAIRE

To assess sustainability inclusion in engineering curricula in Kuwait, a questionnaire was developed and adapted from the Sustainability Assessment Questionnaire for Colleges and Universities designed by the Association of University Leaders for a Sustainable Future (AULSF, 2009). This reference questionnaire was tailored and shortened to fit the context of Kuwait and the particularity of its Higher Education Institutions (HEIs) while keeping the focus on the inclusion of sustainability in engineering curricula.

The developed questionnaire underwent two stages of review before being publicly published. In the first stage, an initial draft was validated by three subject matter experts who provided relevant and constructive feedback. Some comments were related to the length and clarity of the questionnaire which were addressed by combining questions and easing online navigation. It was also suggested to include discipline specific examples from the Middle East and North Africa (MENA) region. The second review stage consisted of a pilot study to ensure the validity and readability of the questionnaire. The questionnaire was shared online with 12 faculty members from various universities in Kuwait. Whereas most of the participants were excited about the topic and assured us of the clarity of questions, the majority had concerns regarding revealing the name of their institution. Accordingly, it was decided to remove the question related to the name of the institution to assure the participants about the anonymity of their responses.

The final version of the questionnaire included five sections. The first section introduces the participants to the subject and confirms the anonymity of the questionnaire. The second section included an explanatory video to introduce the participants to the research topic using a visually aided method which is usually more preferred than explanatory texts. Section 3 aims to collect demographic data such as age, gender, position, and whether the participant is involved in teaching an engineering program or not. All questions in section 3 were multiple choice questions where the user selects one choice.

Section 4 of the final questionnaire consists of 14 questions aimed at recording perceptions towards the current level of integration between sustainability concepts and the participant's institution's curricula. It assesses multiple dimensions including (1) the currently offered engineering curriculum in the participant's educational institution, (2) research and scholarships, operations, (3) faculty, staff development, and rewards, and (4) administration, mission and planning. Section 4 questions were of different types including multiple choice, checkboxes, short and long answer open-ended questions, and scale-based questions. Finally, section 5 included only one open ended question and aims at collecting general

feedback about the participant's perceptions related to Sustainability in Kuwait's Higher Education Institutions' Curricula.

The questionnaire was shared using multiple direct and indirect, formal and informal channels. Many responses were collected on multiple occasions such as conferences, academia gatherings, and social media. Meetings with random faculty members from various universities in Kuwait were conducted on several occasions to explain the survey objectives and motivate them to fill in the survey objectively with the main aim of increasing the response rate and ensuring most public and private universities in Kuwait are represented in the responses. In addition, official letters and emails were sent to Public and Private Universities in Kuwait through their official channels requesting to disseminate the questionnaire to all educational institutions and colleges offering one or more engineering program. Moreover, for quick access, a quick response (QR) code was generated for easy sharing.

SURVEY RESULTS AND ANALYSIS

The population under investigation in this research is the set of all faculty employed in private and public Kuwaiti higher education institutions which yields to a population of around 2950 persons. This estimated number was obtained from counting the faculty members listed on the various universities' websites and other secondary resources. Considering the extensive and diverse nature of this population, a simple random sampling method was deemed most suitable for the research design, as it enables the random selection of individuals possessing pertinent attributes that are crucial to achieving the study's objectives. The best sample size is estimated accordingly based on the population size and confidence level selected. Considering a margin of error of 10%, the minimum sample size required from the targeted population is 94.

As with any survey, this study may be subject to limitations such as response bias, insufficient depth in capturing attitudes, and variations in cultural and contextual perspectives. However, these challenges were mitigated through the careful design of the questionnaire and the involvement of academics from diverse cultural backgrounds, disciplines, and universities.

Data collection was open for a period of four months starting from October 2023 through January 2024 which yielded a collection of 106 responses. Numerical data collected was analyzed using Google Forms® and Microsoft Excel®. Open ended questions were analyzed using the qualitative data software NVivo®. Within the context of this paper which focuses on analyzing the inclusion of sustainability in engineering curricula in Kuwait, the results of only section 3 (demographics) and seven out of the 14 questions of section 4 are presented and discussed. The selected questions are listed in the Appendix.

Demographic Results

The results of section 3 of the survey show that most of the respondents are from the age category 20 to 29 (34%) followed by the category 40 to 49 (31.1%) then the category 30 to 39 (26.4%) and the least are above 50 years (8.5%). Gender wise, the majority are male participants with 72.6% while 27.4% are females. Moreover, 98.1% of the participants are academics who are involved in teaching/delivering courses from an engineering program curriculum. The previous figures are compatible with the demographics of the overall faculty members' population in Kuwait which includes master's and PhD holders. Being mostly faculty members involved in teaching engineering programs (98.1%) provides validation for the participants' responses to the questions of sections 4 and 5 of the survey.

Sustainability in Kuwait's HEI's Engineering Curricula

The first question of section 4 of the survey asks respondents to indicate the extent to which their institution offers courses which address topics related to sustainability. Almost 37.7% of the participants expressed that the offering of sustainability related courses is of great deal at their institutions, 36.8% revealed that their institutions offer a little sustainability within their courses and 19.8% ranked their institution as offering quite a bit of sustainability topics within its courses. The rest were not sure about whether sustainability is offered or expressed that sustainability is not covered at all. Figure 1 shows the distribution of responses.

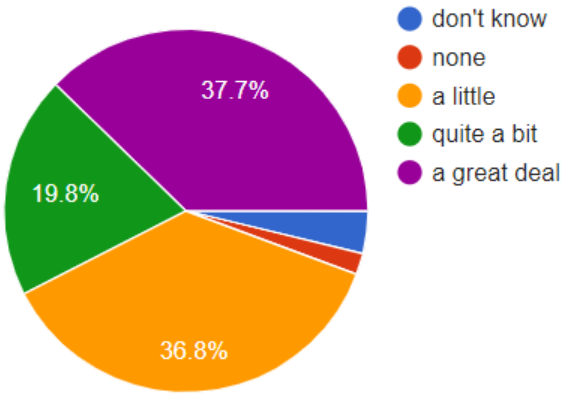


Figure 26. Distribution of responses to the question: Indicate the extent to which your institution offers courses related to sustainability.

An open-ended follow-up question asked participants to fill in the name and code of the courses(s) in which sustainability topics are taught in their institution. Figure 2 shows the occurrence percentage of course titles out of 78 total extracted words. Analyzing the answers shows that most of the mentioned courses are “supporting courses” (e.g., general engineering, graduation projects, etc.)” (38.46%), “ethics” (25.64%), and “environment” (19.23%). Moreover, going over the responses, most of the responses mention one course. On the other hand, the course codes provided were of different encoding which validates that the survey data represents various universities in Kuwait.

Another open-ended follow-up question asked the participants: “What courses do you believe are essential to educate about sustainability and are not being taught in your institution?”. Figure 3 shows the recurrent words’ percentage out of 110 extracted words. Interestingly, courses which are considered as fundamental to sustainable development such as “sustainability”, “energy”, and “renewable” acquired the highest occurrence percentages which indicate a lack of fundamental sustainability concepts in the participants’ engineering curricula.

It is here worth mentioning that Figure 2 and Figure 3 present the results of two inverse questions (sustainability related courses taught vs. not taught in the participant’s institution). Whereas the first question (courses taught) led to 78 extracted words, the second one led to more extracted words (110 words) which indicate that participants are more aware of sustainability related courses not taught in their institution compared to those taught. Moreover, the occurrence of words in these two figures are reversed in the sense that words with the highest occurrence percentage in one figure appear in the lower range in the other one and vice-versa (e.g. “sustainability” occurred 38.46%x110 = 42 times in the list of courses not taught in the institution versus 3.85%x78 = 3 times in the list of courses taught in the institution). This provides a validation for the results.

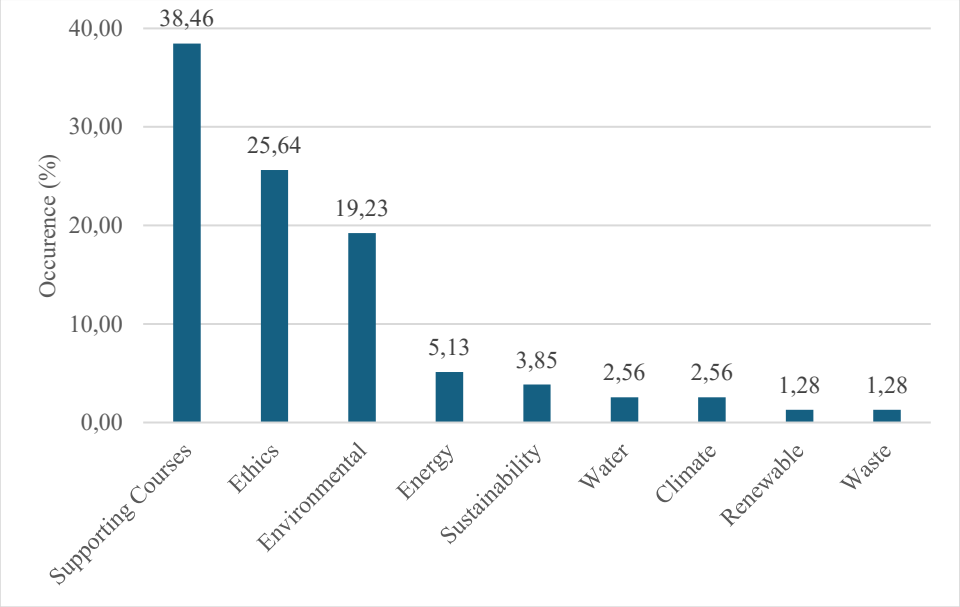


Figure 27. Occurrence of course titles in responses to the question: List any courses you are aware of in which sustainability related topics are taught in your institution

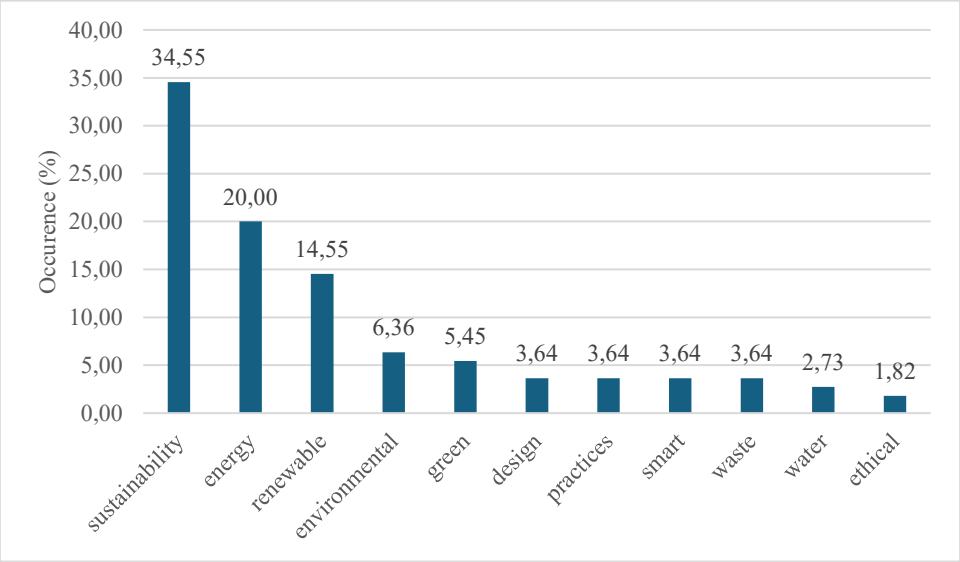


Figure 28. Occurrence of stated courses in responses to the question: What courses do you believe are essential to educate about sustainability and are not being taught in your institution?

One additional question in Section 4 asked the participants: “Do you believe undergraduates are required to take a course(s) on issues related to the environment or sustainability?”. Participants almost unanimously (98.1%) responded with a “yes” to this question. This question was followed by the following open-ended question: “Justify your response to the previous question and please explain why you believe undergraduates are or are not required to take a course(s) on issues related to the environment or sustainability?”. Table 1 shows the recurrent words’ frequency and their percentages in the answers to this question after analyzing them. The answers were mostly within the context of “Important” (32.9%), “Knowledge” (21.1%), “Future” (12.3%), “Environment” (10.5%), and “Issues” (10.1%).

Looking at the results of the five questions discussed above, one may conclude that engineering faculty members who participated in the survey believe almost unanimously that students must be exposed to courses related to the environment or sustainability due to their importance to the future, environment, and the world in general. As for the engineering curricula they deliver, the participants revealed that there are some sustainability topics being covered mostly as part of introductory courses or graduation projects; however, sustainability is not incorporated across the whole curriculum since most participants mentioned none, one, or at most two courses. Moreover, it is evident that some curricula are still not incorporating fundamental discipline-based sustainability courses such as renewable and green energy.

Table 10. Occurrence of stated reasons in responses to the question: Justify your response to the previous question and please explain why you believe undergraduates are or are not required to take a course(s) on issues related to the environment or sustainability?

Word	Count	Occurrence Percentage (%)	Similar words
Important	75	32.89	demand, need, required, requirement, requirements, requiring, mandatory, basic, crucial, essential, importance, important
Knowledge	48	21.05	know, knowledge, learn, learning, aware, awareness, understand, understanding, study, take, taking, teaching
Future	28	12.28	future
Environmental	24	10.53	environmental, environmentally, environment
Issues	23	10.09	issues, problem, problems
World	16	7.02	global, globally, human, humanities, world, worldwide
Practices	14	6.14	practices, practicing, skills, use, used, using
Sum	**228**	**100.00**	

Established Structures Related to Sustainability

One question of Section 4 in the survey enquired whether the participant's institution established multidisciplinary and interdisciplinary structures (such as an institute or center) for research, education, and policy development on sustainability issues. Most participants (62.3%) declared that their institution has such structures, while 22.6% mentioned that such structures haven't been established yet and 15.1% were unaware whether such structures exist in their institution or not.

A follow-up open-ended question asked the participants to elaborate more about the established structures (for research, education, and policy development on sustainability issues) in their institution. 63.2% of participants who answered "yes" to the previous question described the established structure in its second part. Most answers were related to support and collaboration (45.10%), funds (29.41%), and seminars, conferences and workshops (19.61%). Table 2 shows the words' frequency and their occurrence percentages in the answers for this question. Interestingly, there is no significant indications about well-established structures or centers that governs the implementation of sustainability concepts in the Kuwaiti HEIs and most of the answers are related to indirect support through

encouragements, funds, seminars, conferences, etc. With the absence of such structures, the incorporation of sustainability in the curricula would remain at a low scale, uncontrolled, unassessed, and non-monitored which limits its development pace and potential to match the national and international standards of education for sustainable development.

Table 11. Occurrence of stated structures in responses to the question: Please explain by describing the institute or center that was established by your institution for research, education and policy development on sustainability issues

Word	Count	Occurrence Percentage (%)	Similar words
Support & Collaboration	23	45.10	collaborates, collaborating, collaboration, assist, encourages, help, support, supports, serves
Funds	15	29.41	funding, funds, support, supports
Seminars/ Conferences	10	19.61	seminars, conferences, courses, forms, webpage, documents, reports
Planning	3	5.88	planning, programs, projects
Sum	**51**	**100.00**	

CONCLUSION

In this paper, the critical role of engineering higher education institutions in Kuwait in advancing sustainability to serve the Country's National Development Plan (2035 Vision) is investigated. The findings reveal that while sustainability concepts are present in the engineering curricula of the faculty members who participated in the study, they are often fragmented and lack a cohesive framework for integration and assessment. Faculty members recognize the importance of incorporating sustainability into engineering education and have made efforts to introduce these principles through various courses and extracurricular activities. However, significant challenges remain, including a lack of internal structures or centers governing a comprehensive sustainability education.

To enhance the effectiveness of sustainability integration in engineering curricula, it is essential for Kuwait's higher education institutions to develop a clear and unified framework that outlines the delivery and assessment of sustainability concepts across all programs. This would not only equip future engineers with the necessary skills to address global challenges but also align educational practices with the United Nations Sustainable Development Goals. Moving forward, collaborative efforts among faculty, curriculum developers, and policymakers will be crucial in fostering an educational environment that prioritizes sustainability, ultimately contributing to a more sustainable future for Kuwait and beyond.

Among other approaches to incorporate sustainability in engineering curricula, a Conceive, Design, Implement, and Operate (CDIO) program is certainly a strong option. A CDIO program ensures engineering students pass through all stages of product development and in turn, when properly implemented, helps students develop a holistic understanding of the environmental, social, and economic impacts of engineering solutions. This is particularly emphasized in CDIO standards 1, 2, 3, 5, and 11 focusing on sustainability inclusion in each of the conceive, design, implement, and operate stages; active, integrated and student-centered learning which are essential in an education for sustainable development; as well as the importance of continuously assessing sustainability related students' knowledge, competencies, and skills to promote sustainability attitudes in engineering students.

ACKNOWLEDGEMENTS

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APPENDIX – SURVEY QUESTIONS

Demographics

Q1. What is your age? – *20-29, 30-39, 40-49, Above 50.*

Q2. What is your gender? – *Female, Male.*

Q3. What is your position? – *Academic, Non-Academic*

Q4. Are you currently teaching or involved in an Engineering Curriculum? – *Yes, No.*

Assessing Sustainability in Kuwait's HEI's: Selected Questions

Q1.a. Indicate the extent to which your institution offers courses which address topics related to sustainability. (Such topics could include globalization and sustainable development; environmental policy and management; etc.) – *don't know, none, a little, quite a bit, a great deal.*

Q1.b. Please list any courses you are aware of in which such topics are taught in your institution. Please list the name of the course along with its code. Type N/A if not applicable.

Q2. What courses do you believe are essential to educate about sustainability and are NOT being taught in your institution?

Q3a. Do you believe undergraduates are required to take a course(s) on issues related to the environment or sustainability? – *Yes, No.*

Q3b. Justify your response to the previous question and please explain why do you believe undergraduates are or are not required to take a course(s) on issues related to the environment or sustainability?

Q4.a. Have your institution established multidisciplinary and interdisciplinary structures (such as an institute or center) for research, education and policy development on sustainability issues? – *Yes, No, Don't know.*

Q4.b. If your answer to the previous question is YES, please explain by describing the institute or center. If your answer is NO, type N/A for not applicable.

RESILIENCE IN ENGINEERING EDUCATION: EXPLORING INDUSTRIAL SKILLS TOWARDS SUSTAINABLE SYNERGIES

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ABSTRACT

Recent research firmly highlights the necessity of incorporating the perspectives of students and graduates to enhance educational strategies. This approach guarantees that education stays globally relevant and effectively addresses the specific needs of various stakeholders. As a direct outcome, resilience in engineering skills is gaining critical importance, focusing on the essential skills required to create sustainable synergies. Transformative changes in engineering education are driving this trend. This study analyses how resilience in engineering education can transform skills to foster sustainable synergies, focusing specifically on the perceptions of students and graduates in Sweden. Using a deductive approach, the research investigates these perceptions through a survey that includes qualitative questions, employing thematic analysis for the data. The study findings indicate that resilience skills are essential for creating sustainable synergies that benefit students, educators, higher education institutions (HEIs), and industry. However, academics face challenges in teaching engineering students' practical skills that are increasingly in demand rather than focusing on theoretical knowledge. Academics struggle to connect theoretical concepts with the problem-solving and engineering practices needed to enhance global competencies in the industry and maintain competitiveness, thereby providing sustainable outcomes. This issue was noted in a previous CDIO syllabus study in 2014, and surprisingly, a decade later, it continues to be a significant concern. This indicates that higher education institutions and educators still have a gap in pedagogical skills that must be addressed.

KEYWORDS

Industrial Skills, Resilience, Sustainable Synergies, Engineering Education; Students' Perceptions, CDIO Syllabus V3, CDIO Standards: 7-8.

INTRODUCTION

To prepare for future and successful engineers, the CDIO approach addresses the necessity for engineering education to provide the learning required by students developing desired attributes of engineers who can Conceive-Design-Implement-Operate complex value-added engineering products, processes and systems in a modern, team-based environment. CDIO Syllabus has added contemporary themes in Engineering in the previous Version 2, such as Sustainability, Innovation and Globalisation; then Digitalisation, Acceleration and Experiences in the last updated Version 3. The CDIO Syllabus lists knowledge, skills, and attitudes desired by graduating engineers. Personal and Professional Skills such as Analysis with Uncertainty and Attitudes to face Uncertainty are included; however, how can students, educators and Higher Institutions (HEIS) develop sustainable synergies and resilience skills in an accelerated world?

Recent research highlights the importance of considering the “perceptions of students and graduates” to improve educational strategies, ensuring that education is globally relevant and tailored to the specific needs of stakeholders (Rico-Cortez et al., 2024, p. 685). The concept of *resilience* in engineering is gaining traction as it focuses on transforming skills to create sustainable synergies, a trend driven by changes in the educational profile of engineering (Klaassen et al., 2023). This approach differs from traditional engineering education, primarily preparing graduates for lifelong employment (Hazrat et al., 2023). Engineers must develop flexible solutions to manage complex socio-technical systems, enhancing ***ecological synergies and resilience*** (Jain et al., 2019). Consequently, an updated curriculum must adopt a multi-disciplinary or transdisciplinary approach, incorporating the perspectives of both students and graduates (Klaassen et al., 2023).

By emphasising the perceptions of students and graduates, we aim to enhance resilience in engineering education and address ongoing trends within educational institutions (Rico-Cortez et al., 2024). However, there remains a gap in the literature regarding how engineering students articulate and understand their perceptions (Kafri, 2022; Coe-Nesbitt et al., 2021; Farley-Ripple et al., 2018; Fisher et al., 2015). With the growing interest in education that makes a difference, it is essential to consider students' perceptions of academic achievement. This requires interdisciplinary and cross-disciplinary approaches that foster resilience and skills, creating sustainable educational synergies, as defined in this article (Coe-Nesbitt et al., 2021; Henriksson et al., 2016). *Thus, our purpose is to analyse the resilience in engineering education by exploring skills to create sustainable synergies, specifically through the perceptions of students and graduates in Sweden*. To fulfil this purpose, we answer the following research question (RQ):

RQ: What skills are essential for enhancing the resilience in engineering education to reshape students' and graduates' views on sustainable synergies in Sweden?

The remainder of this paper is organised as follows. The introduction offers the background context and objectives of the study. In the second section, we outline the theoretical foundations that underpin this research, while section 3 details the research methodology employed. Section 4 presents the findings of the study. Finally, the concluding section includes a discussion that reflects the study's contributions to theory and practice, acknowledges its limitations, and suggests directions for future research.

THEORETICAL BACKGROUND

Resilience in Engineering Education

Resilience is fundamentally linked to the occurrence of disruptive and often extreme events. The capacity to adapt and learn is vital for developing resilience (Scharte, 2021). Significant inter- and transdisciplinary research has been undertaken regarding resilience, mainly focusing on strategies to enhance it (e.g., Gasser et al., 2021; Rockström et al., 2023; Walker, 2020). Rockström et al. (2023) synthesised pivotal studies on resilience. They identified five essential attributes for building and enhancing resilience across various disciplines and sectors: diversity, redundancy, connectivity, inclusivity and equity, and adaptive learning.

Engaging engineering students in resilience thinking is essential; a critical aspect is learning from failures. Transforming educational skills within the broader framework of problem-based learning can be effective by analysing past academic failures and their implications for developing a capable workforce that meets changed industrial demands (Edmondson & Sherratt, 2022; Foley et al., 2022). This perspective is particularly valuable for acquiring skills that foster sustainable synergies and address complex problems in designing resilient educational systems thinking. Resilience educational systems thinking focuses on understanding and adapting to a changing world. By comprehending how and why systems are changing, we can better develop the capacity to engage with change rather than being victims of it (Walker & Salt, 2006, p. 14). Thus, resilience does not simply mean bouncing back after a disturbance; the concept is more accurately described as robustness or resistance to change, terms that are often mistakenly used interchangeably (Rockström et al., 2023; Winkens & Leicht-Scholten, 2021). Instead, resilience is characterised by adaptive capacity and a forward-looking approach that enables transformation to a different level (Folke, 2016; Folke et al., 2010). This understanding of resilience acknowledges the intertwined nature of ecosystems and humans, which together form conditions for sustainable synergies in complex integrated social-ecological systems (Folke, 2016; Folke et al., 2010; Rockström et al., 2023; Walker et al., 2004).

Skills for sustainable synergies

Our focus on resilience in engineering education emphasises the development of sustainable synergies defined as […] “competencies characterised by an anticipatory perspective and future orientation, the ability to think critically, creatively, and systemically, action competence, ethical sensitivity, and the capability to manage in conditions of change, uncertainty, and risk” (Sterling, 2014, p. 91). Developing skills like reflection, open-mindedness, knowledge integration, and critical thinking is crucial to balancing resilience with interdisciplinary collaboration (Barnett & Jackson, 2020). This suggests that engineering curricula should adopt inter- and multi-disciplinary approaches and consider the views of students and graduates (Klaassen et al., 2023). Today's engineering landscape requires graduates to not only meet rigorous technical standards but also to possess a range of soft skills that enhance their employability. Developing these soft skills is a crucial component of engineering education and training, as Campos et al. (2020) highlighted. This combination of technical knowledge and soft skills is vital for ensuring that engineering graduates are well-prepared to face the diverse challenges of their profession and gain a competitive advantage in the job market. Deep technical and collaboration skills are still valid in the industry. In addition, personal attributes, such as a propensity toward action, integrity, and self-reliance, are important skills that are valid for today's engineers (Crawley, 2014).

Engineering students must be able to effectively communicate their knowledge in different contexts, including academic environments, corporate settings, and research projects. They sometimes serve as skilled "translators," bridging the gap between complex technical concepts and their practical applications. The main objective is to balance engineering expertise and *professional skills* (Winberg et al., 2020).

Students` perspectives on engineering education

Engineering students' perspectives are increasingly seeking a broader standpoint. They have identified critical characteristics for developing learning environments and course activities that effectively support their competence in globally integrated learning (Richter & Kjellgren, 2023, p. 482). Kjellgren and Richter (2021) argued that teaching approaches that emphasise global competence should involve learning environments that are engaging, inclusive, and centred around students. Course activities must be designed to be relevant to real-world situations, incorporate collaborative elements, and be effectively supported and facilitated by instructors (Kerkhoff & Cloud, 2020). The integration of global competence in engineering education offers valuable insights into students' perspectives and experiences during their studies. Furthermore, it critically evaluates students' ideas and suggestions about opportunities for such learning within the field of educational science and proposes strategies for enhancing global competence in engineering education. Engineering curricula must integrate global competence learning to prepare graduates for success in globalised labour markets (Van den Beemt, 2020; Crawley, 2014). Focusing on students' skills (Wang et al., 2019), they are challenged to possess advanced knowledge of global competence is advantageous. However, it also highlights the challenge of representativeness within study populations (Wang et al., 2019). Reskilling students' knowledge is a notable trend, referring to acquiring new skills or updating existing ones to meet the changing demands of the job market (Richter & Kjellgren, 2023). This involves learning new competencies relevant to current or future job roles, while upskilling teaches employees additional skills. Jesiek et al. (2014) examined the "industry competencies" related to students' perceptions of their abilities, particularly in global engineering work. Their research revealed that global engineers frequently face challenges involving technical coordination, negotiation across diverse engineering cultures, and understanding ethics, standards, and regulations. Despite an increasing acknowledgement of the relevance of global competence in engineering professions, scholars have expressed frustration that educational institutions are progressing slowly in developing the global graduates that the industry requires (e.g., Richter and Kjellgren, 2023; Van den Beemt, 2020; Carter, 2020).

This study significantly advances existing literature by presenting a robust approach rooted in a logical framework developed from prior research (Rico-Cortez et al., 2024). It decisively analyses students' skills, academic abilities, and industry competencies, delivering a comprehensive perspective essential for enhancing educational strategies. This approach ensures that education is globally relevant and specifically tailored to the needs of stakeholders. The research suggests that by implementing a framework to assess the resilience of engineering education, we can effectively transform skills and promote sustainable synergies, including insights into student perceptions. **Table 1** presents three key focus areas influencing students' perceptions of enhanced educational strategies.

Table 12. Areas influencing students' perceptions of enhanced educational strategies.

Students' perceptions	e.g., context	e.g., references
Students Skills	Advanced global competence is beneficial and highlights challenges in representativeness within study populations. Reskilling students is essential to meet the evolving job market demands.	(Wang et al., 2019)
Academic Abilities	Higher Education Institutions (HEIs) and teacher training programs should utilise insights into critical skills and their connections to various professional contexts.	(Peng & Kievit, 2020)
Industry Competencies	It is essential in the context of global engineering work.	(Jesiek et al. 2014)

METHODOLOGY

This deductive study uses a qualitative design to emphasise "contextual understanding". Researchers aim to understand behaviour, values, beliefs, and other factors within the context of Resilience (Scharte, 2021, p.17) in Engineering (Edmondson & Sherratt, 2022; Foley et al., 2022). The deductive approach is employed by analysing pre-existing theory, in this case, institutional theory (Bryman & Bell, 2011, p. 411). The study examines students' perspectives in the Swedish education context, focusing on the various skills (Wang et al., 2019), abilities (Peng & Kievit, 2020), and competencies (Jesiek et al., 2014) when the resilience of engineering education, is seen to transform skills and promote sustainable synergies effectively.

Data Collection

Surveying with “qualitative interview questions” can allow researchers to pose questions that respondents can reflect on and answer (Gephart, 2004, p.458). Survey questions addressed the students' perceptions of their education in Sweden, through Engineering Education at Jönköping University; see **Appendix 1**. We used a combination of theoretical sampling and snowball sampling to select our survey respondents. Some respondents were directly contacted based on their involvement at the engineering school, while others were identified through referrals (Bryman, 2011). A code of A1-A17 identifies participants to protect their anonymity **Table 2**.

Table 2. Participants information

Code	Level	Discipline	Time
A1	Master Student	Product design	20 min
A2	Master Student	Industrial engineering	10 min
A3	Master Student	Industrial engineering	24 min
A4	Master Student	Industrial engineering; Design; Chemical engineering;	25 min
A5	Master Student	Engineering management;	10 min
A6	Master Student	Industrial engineering;	09 min
A7	Bachelor Student	Mechanical engineering	07 min
A8	Master Student	Engineering management; Industrial engineering;	09 min
A9	Master Student	Engineering management; Industrial engineering;	40 min
A10	Master Student	Computer science and engineering, Graphic Design;	10 min
A11	Bachelor Student	Mechanical engineering;	10 min
A12	Master Student	Mechanical engineering; Engineering management	11 min
A13	Master Student	Mechanical engineering; Industrial engineering	15 min
A14	Master Student	Industrial engineering	12 min
A15	Bachelor Student	Mechanical engineering	13 min
A16	Master Student	Computer science and engineering	15 min
A17	Bachelor Student	Mechanical engineering	20 min

Data analysis

Data analysis was carried out through a thematic approach, which is common in the students' perceptions (Richter & Kjellgren, 2023, p. 482) and engineering education fields (Edmondson & Sherratt, 2022; Foley et al., 2022). ***Figure 1*** displays our theme analysis and research model. The gathered data was analysed by looking for common patterns, phrases, expressions, and words with relevance to the main themes of our study (Mäntylä et al., 2018). In the first level of coding (L1), data from the surveys were aggregated into superior categories, enabling the identification of patterns, structures, and relationships (Strauss & Corbin, 1990) in which related students' perceptions and contexts from the surveys were interpreted and transferred. In the second level of coding, thematic codes (L2) were extracted from both secondary materials (Teknikföretagen Kompetensunder-Söking, 2022; UNESCO Snapshots,2020) and surveys (Catelani et al., 2021). After gathering data through the survey, we looked at secondary data sources. Identifying thematic codes that align with our theoretical base affected our intended contribution. These themes aimed not simply to describe the

context but rather to be more focused on explaining the internal constructs of our study: the third set of themes derived from Sterling (2014) and the various students' skills (Wang et al., 2019), academic abilities (Peng & Kievit, 2020), and industry competencies (Jesiek et al., 2014) built on the contextual facts presented in section 2.3, themes are abstract and subtle expressions, patterns, processes that explain a phenomenon (Saldana, 2013, p.14).

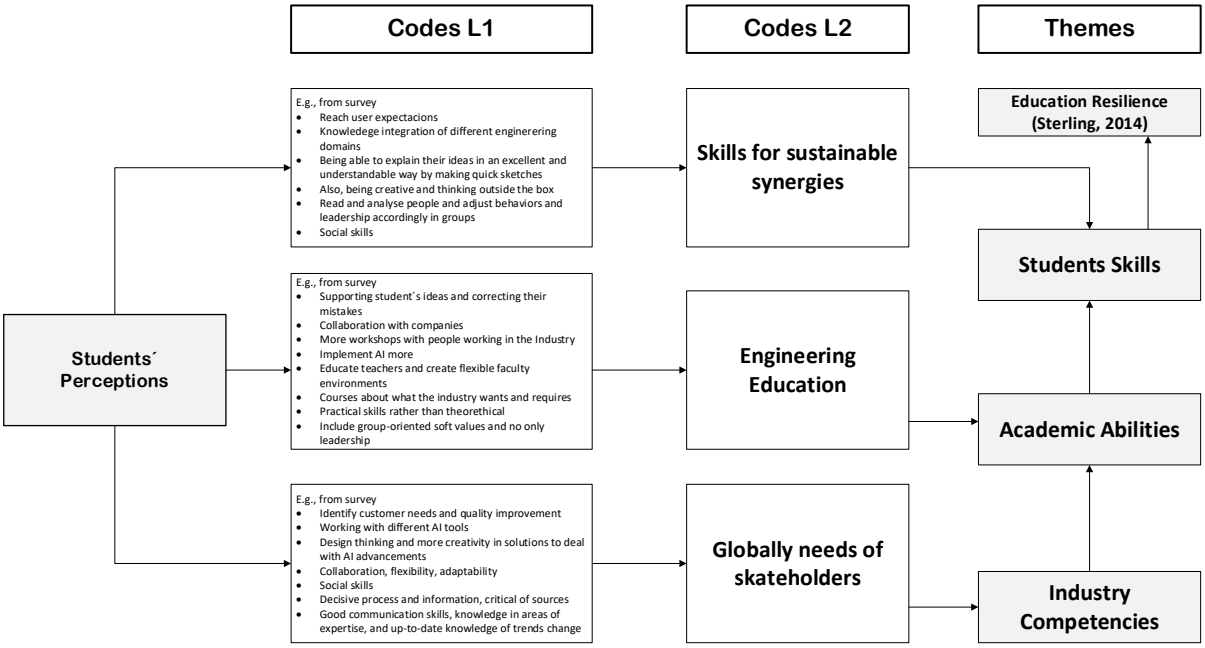


Figure 29. Themes analysis and research model

Thus, analysing our data with a deductive mind, we let the survey questions capture valuable insights. We avoid too much hanging on literature review constructs, blinding us from the subtle aspects of the engineering education resilience phenomenon. According to Mishra and Dey (2022), it is essential to maintain some distance from existing literature when framing research objectives, creating interview guides, and analysing data. Our study follows Guba and Lincoln (1994) to confirm the quality of this study for qualitative interpretative research, meaning credibility (internal validity), transferability (external validity), dependability (reliability) and confirmability (objectivity). Validity and reliability are critical considerations in paradigm findings from research design (Creswell, 2014). To prevent researcher bias, the first coding level was done independently by one team member, and the second was done separately by another team member. Any inconsistencies were thoroughly discussed within the team until a consensus was reached. This iterative approach ensured the reliability and high quality of the analysis (Catelani et al., 2021). Internal validity (Guba & Lincoln, 1994) was established by triangulating data from interviews and secondary documents.

FINDINGS

We provide a brief review of the resilience of Swedish engineering institutions by examining students' skills, academic abilities, and industry competencies. This assessment focuses on the strength of industrial engineering education, highlighting how these factors can effectively transform skills and foster sustainable synergies, including insights from students' perceptions. The review is grounded in a framework based on prior research that captures students' perceptions (Rico-Cortez et al., 2024).

Students 'skills

The findings indicate that many students wish to *develop or improve their problem-solving skills* (e.g., A1, A2, A3, A4, A5). Crawley (2014) argues that this desire is logical, as the skills of a genuine engineer primarily involve systematic problem-solving techniques in design. These techniques combine problem-solving and technological skills with personal creativity and judgment gained from experience. Students believe that *integrating knowledge across engineering domains would enhance their problem-solving skills* (e.g., A9, A10).

The second skill that students prioritised was *leadership and social skills*, which they found are closely related to communication skills (e.g., A4, A10, A11, A12). Several students desired *to feel more confident when sharing their ideas or presenting projects* (e.g., A10, A12, A4, A6). Students have identified *creativity, design thinking, and critical thinking as essential skills for professional development (e.g., A1, A2, A10, A12, A13)*. Furthermore, 50% of the students indicated that *management skills are associated with time management and the ability to make quick decisions*. Interestingly, artificial intelligence was not considered a high priority. It was noted as essential *to adapt to new systems and their changes, particularly in AI development* (e.g., A14, A15, A16). Only a student (A10) recognised "*resilience as essential for learning how to confront the world's challenges in both personal and professional life*." Students also noted that *being decisive involves processing much information and critically evaluating sources* (e.g., A1, A6, A17).

Academic abilities

Academic abilities are highly sought after in reorienting teacher training programs. These programs should incorporate insights into critical skills, which, according to Peng and Kievit (2020), are related to the resilience of Higher Education Institutions (HEIs) in various professional contexts. HEIs should improve their feedback systems, as students perceive that *feedback is essential for supporting their ideas and correcting mistakes* (e.g., A1, A2, A6, A7). Students noted that "*enhancing collaboration with companies is essential*" (A10). Holding *more workshops with industry professionals could be beneficial* (e.g., A3, A4, A11, A12). Some students suggested that *HEIs collaborate more closely with industry* (e.g., A10, A14, A17). In their view, *academic ability refers to additional courses focusing on industry demands and requirements* (e.g., A2, A5, A6, A6). Several students expressed the importance of *learning to network and present themselves to future employers* (e.g., A13, A14, A7). They emphasised the need for *environments and facilities that boost their confidence* (e.g., A1, A2). It is crucial to integrate *more "AI into education to keep pace with the new digital era"* (A10). Students emphasised the *importance of training teachers and creating flexible faculty environments to support this transition* (e.g., A11, A7, A8, A9). Students also highlighted that *feedback is essential for supporting their ideas and addressing mistakes* (e.g., A9, A10, A11). When addressing academic resilience, students emphasised the importance of *increasing collaboration with companies and suggested that hosting more workshops with industry professionals could be beneficial* (e.g., A5, A10, A11, A6, A17). Some students also recommend *establishing closer partnerships with industry when necessary* (e.g., A15, A16, 17). HEIs should offer more courses that align with industry demands and requirements (e.g., A16, A17).

Industry competencies

Industry competencies are emphasised by Jesiek et al. (2014) as essential in the context of global engineering work. In students' perceptions, the growing demand for *AI skills that adapt to various industries* (A1-A17) has emphasised the importance of *utilising multiple AI tools*

tailored to meet industry needs (e.g., A2, A3, A4, A5). Additionally, students noted that *design thinking and enhanced creativity are essential for addressing advancements in AI* (e.g., A6, A7, A8, A9). They also highlighted the significance of *understanding customer needs and improving product quality* (A1-A17). Additionally, students acknowledged that the industry values *collaboration, flexibility, and adaptability*, which are essential for academic resilience and should be *incorporated into the academic competency portfolio* (e.g., A5, A7, A8, A9, A10, A12). Students pointed out the necessity of *strong communication skills and the ability to make quick decisions* (A13, A14, A15, A16). Students emphasised the importance of *gaining in-depth knowledge and staying current with evolving work trends* (A1-A17). Students recommended *integrating research with the goal of solving industrial challenges and meeting resilience and sustainable outcomes* (A1-A17). **Table 3** summarises the perceptions of students found in the study.

DISCUSSION AND CONCUSSIONS

This study analysed *the resilience of industrial engineering education in exploring skills to create sustainable synergies, specifically through the perceptions of students and graduates in Sweden*. The study found that essential skills for enhancing the resilience of engineering education and reshaping students' and graduates' views on sustainable synergies in Sweden are lacking. Key skills to improve or develop include design thinking, creativity, management, leadership, problem-solving, AI, and resilience. These are recommended for higher education institutions to adopt and enhance in this new digital era. According to Sharte (2021), adapting and learning are essential for building resilience.

RQ. What skills are essential for enhancing the resilience in engineering education to reshape students' and graduates' views on sustainable synergies in Sweden?

The study revealed that students' perceptions are linked to their ability to quickly adapt to new systems and the changes that come with them, particularly concerning adopting AI development. This finding aligns with version 3 of the CDIO Syllabus, which includes significant updates regarding sustainability skills, innovation, globalisation, acceleration, and digitalisation experiences. Additionally, the importance of confronting uncertainty has been emphasised. However, there is still a gap in understanding the concept of resilience and how to properly prepare engineering students, educators, and institutions for it. Developing anticipatory perspectives and a forward-thinking mindset is essential for tackling global challenges and adapting to the rapid changes brought about by digital trends.

Table 3. Summary of findings, building on students' perceptions

Students' perceptions		
Industry competencies	**Students' skills**	**Academic ability**
Skills Required to Meet Future Demands and Remain Competitive	Design thinking, Creativity, Management, Leadership, Problem-solving, AI, Resilience	Systematic problem-solving techniques in design combine scientific and technological skills with personal creativity and judgment gained from experience.
Higher education institutions (HEI´s) need to enhance their ability to meet the needs of the industry.	Feedback, Collaboration with Industry, AI, educating teachers, practical skills, working with others, and the faculty environment.	Higher education institutions (HEIs) must improve their understanding of industry needs.

Students must develop skills that will keep them an attractive part of the workforce.	User experience, Knowledge integrations in different engineering domains, Communication skills, Creative thinking, Project management, and social skills	Academic capability must incorporate more AI in education to adapt to the new digital era. Teachers should create flexible and confident learning environments.
Skills Relevant to Aligning with Global Industry Demand for Engineers	User experience, AI (8), Design Thinking, *Resilience*, Collaboration, and making decisions fast.	The ability to strengthen partnerships with industry for academic purposes.
Unnecessary skills result in inefficient use of resources and capabilities.	Material calculations and stress analysis by hand. Learning many formulas that feel inapplicable, Entrepreneurship	Students asserted the critical necessity of integrating AI into education to navigate the digital era effectively. Students underscored the urgent need for comprehensive teacher training and the establishment of flexible faculty environments to facilitate this essential transition.
Recommendations for the Education of the Future	Focus on creativity and Problem-solving. Integrate Industry and research, collaboration with industry, AI,	The academic emphasis on understanding customer needs is crucial for improving product quality.
Desired skills that companies will need in 5-10 years	User needs, quality improvement, AI, design thinking, creativity, good communication, and decisiveness.	Academies must integrate research to solve industrial challenges and achieve resilience and sustainable outcomes.

The study revealed that innovation and systems are faster than ten years ago. However, we still face challenges in educating engineering students with practical skills instead of just theoretical knowledge, which is increasingly demanded. The study revealed that students find engineering theory often requires memorisation of formulas for exams, making it difficult for them to connect this theory to practical problem-solving and real-world engineering practice. This disconnect was highlighted in students' perspectives on teaching and learning by Crawley et al. (2014), and surprisingly, it remains an issue even after a decade. Students perceive a disconnect between practical skills and theoretical knowledge, expressing concerns that they must "learn so many formulas that feel inapplicable" and that "material calculations and stress analysis by hand are unnecessary skills" (A3-14). This suggests that engineering educators may neglect critical pedagogical needs, placing significant pressure on academics to provide education that effectively meets industrial competencies. For instance, students indicate that even digital learners face this gap, highlighting the need for institutions and educators to rethink their teaching approaches. In this context, resilience can be more accurately described as resistance to change.

The study highlighted a crucial aspect of AI and digitalisation: the need for education on effectively managing Artificial Intelligence (AI). Students stressed the importance of teaching proactive strategies for using AI instead of merely making its use "illegal" (A11). Engaging industrial engineering students with resilience thinking is vital to help them adapt quickly to new systems and understand how they change (A10).

The study revealed that students desire the ability to understand past and future trends. As noted by A10, “With the willingness to learn both old and new work trends, it is clear how digitalised the world is becoming over time.” This perspective aligns with the CDIO syllabus V3 (4.1.4), emphasising that students should be aware of historical and cultural contexts. Additionally, students continue to face challenges with leadership and social skills, particularly in communication within international environments. This is especially true for those who struggle to adapt to new educational systems that feature multicultural settings.

Implications
Collaboration with Industry: Students emphasise that collaboration with industry is crucial for their education. Understanding the needs of both industry and society is essential for becoming a successful engineer. In addition to technical skills, management and business skills are also necessary. Students mentioned that efficiently organising work materials is critical, and the ability to do so using AI is increasingly valuable (A8, A11, and A16).

Academic ability: Feedback plays a vital role in educational development. Higher Education Institutions (HEIs) should support students by guiding them and creating an environment where they can express their ideas without fear of criticism. It is essential for students to feel safe to explore and innovate.

Future research must incorporate students' perceptions of the resilience of Higher Education Institutions (HEIs) strategies in the present study, with research demonstrating that building competence and reliability for future employers is required—comparative studies that demonstrate the integration of the different perspectives from relevant stakeholders: students, academics and industry managers. The sample size of 17 responses limited the study. Future research should aim to increase the number of responses to enable more in-depth analysis.

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APPENDIX 1: SURVEY QUESTIONS

Skills to Improve	**Higher Education Institutions (HEIS) should work on improving their programs and practices.**	**Skills the Industry Seeks or Desires**
What other (like “soft”) or engineering skills should students have to increase their competitiveness in the industry?	How could the Higher Education Institutions (HEIs) improve the preparation of tomorrow´s engineers?	What skills does the industry or (research project) currently look for in engineers?
Which skills, categorised as soft or hard, are considered unnecessary in engineering education?	From your perspective, what are the anticipated skills or competencies, such as digital skills, sustainability, AI expertise, and circularity, that companies will require in the next 5 to 10 years?	What skills do you want to develop or improve for your daily work?
		Desired skills that companies will need in 5-10 years

UNITED BY DESIGN: MODULAR AND FLEXIBLE LEARNING FOR UNDERGRADUATE ENGINEERING PROFESSIONAL PRACTICE

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ABSTRACT

Professional practice coursework is a cornerstone of engineering education, particularly where access to industry placements is limited. The Faculty of Engineering has consolidated its final-year discipline-specific professional practice units into a unified framework supported by a suite of online, self-paced modules. These modules, which cover topics such as ethics, sustainability, and project management, are aligned with the CDIO (Conceive–Design–Implement–Operate) framework to provide consistent, scalable learning across engineering disciplines. The modules include a mix of readings, case-based tasks, videos, and auto-graded quizzes to engage students and support active learning. This case study explores the design and initial evaluation of these modules from an educational designer's perspective, specifically examining how CDIO principles were applied to structure the learning experience. Early engagement analytics revealed discrepancies between the intended and actual use of the modules. Analysis of student behaviour indicated early access to content with minimal re-engagement, a limited uptake of optional materials, and quiz attempts that were often disconnected from the broader learning experience. These findings suggest that while the design aimed to encourage active participation, sustained engagement with the material was less evident than anticipated. This paper discusses the implications of these findings for online module design, particularly in the context of professional practice education. The study highlights the need for further investigation into how learning analytics can inform design iterations, ensuring that CDIO principles are fully realised in digital learning environments. By focusing on behavioural data and design alignment, this study contributes to a broader understanding of the challenges and opportunities in creating engaging and effective online learning experiences for large, diverse student cohorts.

KEYWORDS

Professional practice, Engineering education, Online learning modules, Learner analytics, Standards: 1-5, 7.

INTRODUCTION

Practical professional experience is an integral part of accredited professional engineering degree programs in Australia, offering students hands-on, immersive learning in their field. Despite the persistent high demand for professional engineers in Australia (Bell & Briggs, 2022; Kaspura, 2019; Australian Parliament Senate Education, 2012), students have struggled to secure industry placements and internships (Sher & Sherratt, 2010). Therefore, coursework exposure to engineering professional practice is still an integral part of engineering programs. To address this challenge and enhance the student experience, Monash University's Faculty of Engineering has streamlined its Professional Practice offerings within undergraduate programs, making it more consistent, flexible, and accessible for students to gain exposure to industry professional practice topics. A key feature of this new approach is a common set of self-paced online modules that all engineering students complete, designed to help them connect with their future profession.

Unified Professional Practice Offerings

Engineering students can now choose from a range of new Professional Practice units (see Table 1) pursue industry experience pathways that suit their preferred mode of engagement. This expanded framework enables students to align their industry experience more effectively with their interests and career aspirations. There is a tailored option for students whether they prefer working in student teams, engaging in work-integrated learning, or participating in the Co-op program. The units listed in Table 1 replace the previously segregated and department-managed Professional Practice units, providing students with consistent experiences regardless of their engineering specialisation. Table 2 provides further information about the purpose of the units, in the form of the shared learning objectives.

Table 1: Professional Practice offerings at Monash University Engineering

Professional Practice (PP) stream	Description
Curriculum embedded (abbreviated as PP(CE))	A classroom-taught unit where theory meets real-world challenges, acting as the crucial bridge between engineering studies and industry.
Student teams (abbreviated as PP(TEAMS))	Student learning is hands-on with authentic, real-world projects and challenges, working in diverse, multi-disciplinary teams. This is offered exclusively to current members of Engineering and Information Technology (IT) student teams. These members can be undertaking any degree at Monash.
Work integrated learning (abbreviated as PP(WIL))	Students are immersed in real-world scenarios through an unpaid internship, applying their knowledge to actual industry challenges in a professional setting.
Co-operative education (abbreviated as PP(COOP))	Students are immersed in real-world scenarios through a paid internship, applying their knowledge to actual industry challenges in a professional setting.

While the nature of the industry experience associated with each of the Professional Practice units is different, all students from all specialisations will be engaging with a newly developed set of online self-paced modules, including one discipline/specialisation specific module. The suite of self-study online modules are a key focus in this paper, and support the completion of the Unit Learning Objectives for the Professional Practice units (shown in Table 2).

These Professional Practice units focus on essential skills, including problem-solving, ethical decision-making, teamwork, and communication, aligning with CDIO standards framework and accreditation standards from bodies such as Engineers Australia (Engineers Australia, 2019) and the Engineering Accreditation Council Malaysia (Registration of Engineers Act 1967 [Revised 2015], s. 10, 2015). Integrating the United Nations Sustainable Development Goals (United Nations, 2016, 2017), these units emphasise sustainable, socially responsible engineering practices. By the end, students are expected to understand their professional responsibilities and be ready to lead and innovate for positive societal and environmental impact.

Table 2: Most recent published learning outcomes for PP(CE), PP(TEAMS), PP(WIL), and PP(COOP). Accessed 26 Nov 2024 (Monash University 2024a, 2024b, 2024c, 2024d). These have been mapped to the corresponding online self-paced modules.

Learning Outcomes **(related CDIO Standards # in brackets)**	Related module
1. Critically evaluate the roles and obligations of engineers in society and assess the health, safety, legal and cultural impacts of engineering work.(#**1)**	[SOC, LAW, RISK]
2. Integrate human, social, environmental and economic sustainability, proposing innovative solutions for sustainable development in engineering projects.**(#1)**	[SOC, SUST, FIN]
3. Reflect upon ethical issues with depth, developing a framework for ethical decision-making that reflects the profession's values and Engineers Australia and the Board of Engineers Malaysia's Code of Ethics in engineering practice.**(#2)**	[ETH, LAW]
4.Demonstrate advanced collaborative skills, leading and participating in teams effectively to deliver high-quality outcomes while fostering a culture of inclusivity and mutual respect.**(#1, #4)**	
5.Communicate complex engineering concepts and solutions effectively, employing a range of modalities to engage diverse audiences and facilitate informed decision-making in technical and lay contexts.**(#4)**	
6. Plan projects strategically, using established project and financial management methods to deliver project plans that meet quality, budget and time requirements.**(#3, #5, #7)**	[PJMT, FIN]
7. Demonstrate a commitment to lifelong learning, proactively seeking out emerging knowledge and skills to remain at the forefront of engineering innovation and professional development.**(#8)**	[all modules]
8. Demonstrate professional skills specific to the discipline, employing modern tools and evidence-based approaches to address and resolve pressing engineering challenges.**(#3, #7)**	[AERO, BMED, CHEM, CIV, ESCE, ENV, MSE, MECH]

Members of the educational design team were partnered with subject matter experts in developing a set of online professional practice modules embedded into four Professional Practice units. These modules cover seven core topics: Engineers & Society (SOC), Project Management (PJMT), Finance & Economics (FIN), Risk Management (RISK), Sustainability (SUST), Ethics (ETH), and Engineers & the Law (LAW). Students also complete a discipline-specific module for their engineering specialisation: Aerospace (AERO), Biomedical (BMED), Chemical (CHEM), Civil (CIV), Electrical & Computer Systems (ECSE), Environmental (ENV), Materials (MSE), and Mechanical & Mechatronics (MECH). Each module includes online quizzes that can be attempted twice, with baseline feedback such as correct/incorrect indicators and a numerical grade to inform students prior to their second attempt. More detailed feedback is released at the close of the quizzes in Week 10, enabling flexibility in meeting deadlines. Each module assessment has a total weighting of 3%.

CDIO & LEARNING DESIGN: EDUCATIONAL DESIGNER'S PERSPECTIVE

These online self-paced modules were set up in Moodle and included readings, real-world case studies and scenarios, video lectures, and interactive tools (e.g., H5P and GeoGebra). The design, guided by the CDIO principles outlined in Table 3, intended to create a robust curriculum that prepares students for the challenges of modern engineering.

Table 3: Design principles aligned with CDIO Standards for enhancing learner engagement in online self-paced modules

Design principles		**Implementation (CDIO Standards # in brackets)**
Learner-centeredness	Scaffold content to learner's needs and goals, facilitating a foundation for deep engagement	Offer core content and optional enrichment learning activities within modules to address the diverse needs of learners (Sanchez-Gordon & Luján-Mora, 2020). Foundational knowledge on the key professional practice skills provided to support students in their placements or course work (Crosthwaite, 2021). **[#2: Learning Outcomes; #3: Integrated Curriculum]**
Engagement through interactivity	Include interactive elements, such as applets, quizzes, and forums, to foster engagement	Embed quizzes and formative applets for immediate reinforcement of learning and opportunities for active learning (Hernández-de-Menéndez et al, 2019) and prompted reflections. Shared forums for all Professional Practice units for interaction with peers and teaching staff (Rivera et al, 2024). **[#8: Active Learning]**
Inclusive learning environment and learner autonomy	Cultivate a learning environment that supports diverse learners	Provide module materials in various formats and ensure accessibility (Rao, 2021). Students can access content and assessment online and on-demand. Multiple attempts at the quizzes enabled students to learn from mistakes. **[#5: Design-Implement Experiences; #7: Integrated Learning Experiences]**
Outcome oriented assessment	Develop assessments that align with the learning objectives	Provide clear descriptions of assessments that demonstrate the alignment of the task to the learning objectives. (Biggs, 2003) [#11: Learning Assessment]
Authentic learning	Contextualise theory with practical examples, scaffolding the application of concepts to integrated, real-world scenarios	Incorporate real-world case studies to connect theoretical concepts with practical application. (Roach et al, 2018) **[#4: Introduction to Engineering; #8: Active Learning]**
Feedback mechanisms for continual improvement	Seek input from user/target audience for improvements	Launch a dedicated anonymous feedback system available at the end of every module. Other feedback tools, e.g. early semester feedback, student evaluation of teaching and units (SETU) provide further opportunities for anonymous feedback (Nair et al 2012) **[#12 - Program Evaluation]**

The design incorporates features that empower students by prioritising autonomy, learner-centered approaches, and interactive elements, ensuring a tailored experience that meets diverse needs. It had been set up to foster real-world connections through authentic learning, encouraging critical thinking and problem-solving. Assessments were developed to be strategically focused on measurable outcomes and directly tied to engineering goals, while on-demand feedback drives ongoing progress and growth.

CDIO Connection

CDIO principles extend beyond the domain of engineering design, and can impactfully influence educational design. Each phase (Conceive, Design, Implement, Operate) contributes to the development of effective and engaging learning modules.

Engagement Goals Versus Reality

When initially designing the online self-paced, auto-graded modules, the intention was to foster meaningful, sustained engagement through strategies that emphasised active learning, interactivity, and relevance to real-world industry practices. The following strategies were incorporated:

1. **Active Learning**: To keep students actively engaged, interactive elements such as quizzes, applets, and shared forums were integrated into the modules. The goal was to allow students to apply what they learned in real-time, reinforcing learning while offering opportunities for peer interaction and social constructivism.
2. **Auto-graded Tasks**: To provide immediate feedback and foster a sense of progress, all attempted tasks were auto-graded. This was particularly important in a self-paced online learning environment where students can sometimes feel disconnected from their learning community.
3. **Industry Relevance**: Case studies, practical examples, and real-world scenarios were included to make the learning experience relevant and connected to the field of study. This would help students see the applicability of their learning beyond theoretical knowledge and strengthen their connection to their chosen engineering specialisation.

An analysis of learner engagement data for the suite of online modules revealed that students' engagement behaviour differed from initial expectations.

LEARNER ANALYTICS AND UNSUPERVISED MACHINE LEARNING (CLUSTERING)

This study leverages Learner Management System activity data logs to explore how learners interact with each module element, the timing and intensity of their engagement, and their progression through each of the modules. Feedback surveys did not have sufficient responses to draw conclusions. Hence for now, we will focus on a quantitative analysis of the learner engagement.

The joint grid visualisation presents a structured way to explore relationships between two numerical variables while also providing insights into their individual distributions. In this case, the main grid consists of a set of bivariate scatter plots, showing the relationship between two metrics:

- **Horizontal axis**: The number of visits to each page in the module.
- **Vertical axis**: The number of visits per day throughout the semester.

Marginal plots that display the univariate distributions of these variables are also shown:

- The **bottom marginal plot** shows the distribution of page visits per module.
- The **right marginal plot** shows the distribution of module suite visits per day, which is also **colour-coded by Professional Practice unit**, allowing for visual differentiation between units.

The common module pages are ordered sequentially from left to right and labelled as: Engineers & Society (SOC), Project Management (PJMT), Finance & Economics (FIN), Risk Management (RISK), Sustainability (SUST), Ethics (ETH), and Engineers & the Law (LAW).

Similarly, the discipline-specific modules are labelled Aerospace (AERO), Biomedical (BMED), Chemical (CHEM), Civil (CIV), Electrical & Computer Systems (ECSE), Environmental (ENV), Materials (MSE), and Mechanical & Mechatronics (MECH).

This visualisation facilitates the tracking of engagement trends, such as whether higher page visits within a module correspond to increased overall activity across the module suite or whether certain Professional Practice units exhibit distinct patterns of engagement over time.

Furthermore, leveraging unsupervised machine learning methods allows for the identification of broad patterns in learner behaviour. These methods can cluster students into distinct engagement groups based on their activity profiles, revealing trends such as consistent versus sporadic engagement or preferences for particular types of content.

A broad comparison of learner trajectories through the self-paced online Professional Practice modules and learning activities can be made using clustering. The analysis used the timestamps for each interaction recorded to reflect the sequential order of learner progression through different online learning module items. The timestamps for each interaction sequence were adjusted so that the first interaction with the module was treated as the starting point, with subsequent interactions measured relative to this time. These sequences were categorised by type of module items (lesson, H5P, quiz) and organised in a table, with each row representing a learner's progression through a single module, and columns containing timestamp sequences (in nanoseconds) related to different module item types.

Since interactions by module item type were considered together in the analysis, and noting that differences in levels of recorded engagement could unfairly favour particular item types, a normalisation treatment was applied to the columns. The normalisation process calibrates all values to fall within a consistent range (typically between 0 and 1).

Each student’s timestamp sequences for engaging with module items can vary greatly in length, and potentially can be quite long. For the purposes of visualisation, a dimension reduction operation called principal component analysis (Kherif & Latypova, 2020) was used to optimise the handling of the timestamp sequences. Principal component analysis (PCA) produces a consolidated representation of the timestamp sequences which enables the flexibility to project each student’s record of engagement with module learning items into the two-dimensional space (via the helper principal components). By using the principal components, we can plot each student’s interaction with a module as a single data point, and observe relationships to other students.

Key Findings (From Joint Grid Visualisation)

Common modules:

- Data indicates that the opening pages of each topic in most modules receive high traffic, especially early in the semester, aligning with the detected peaks. Engagement activity (show by the shading of the cells in the grid) seems to consistently decline rapidly after the opening set of pages.
- The modules vary in length, and this appears to be a factor in overall student module engagement depth. The common modules that are mapped to later in the semester timeline (Ethics and Engineers & the Law), are also longer and more content intensive.

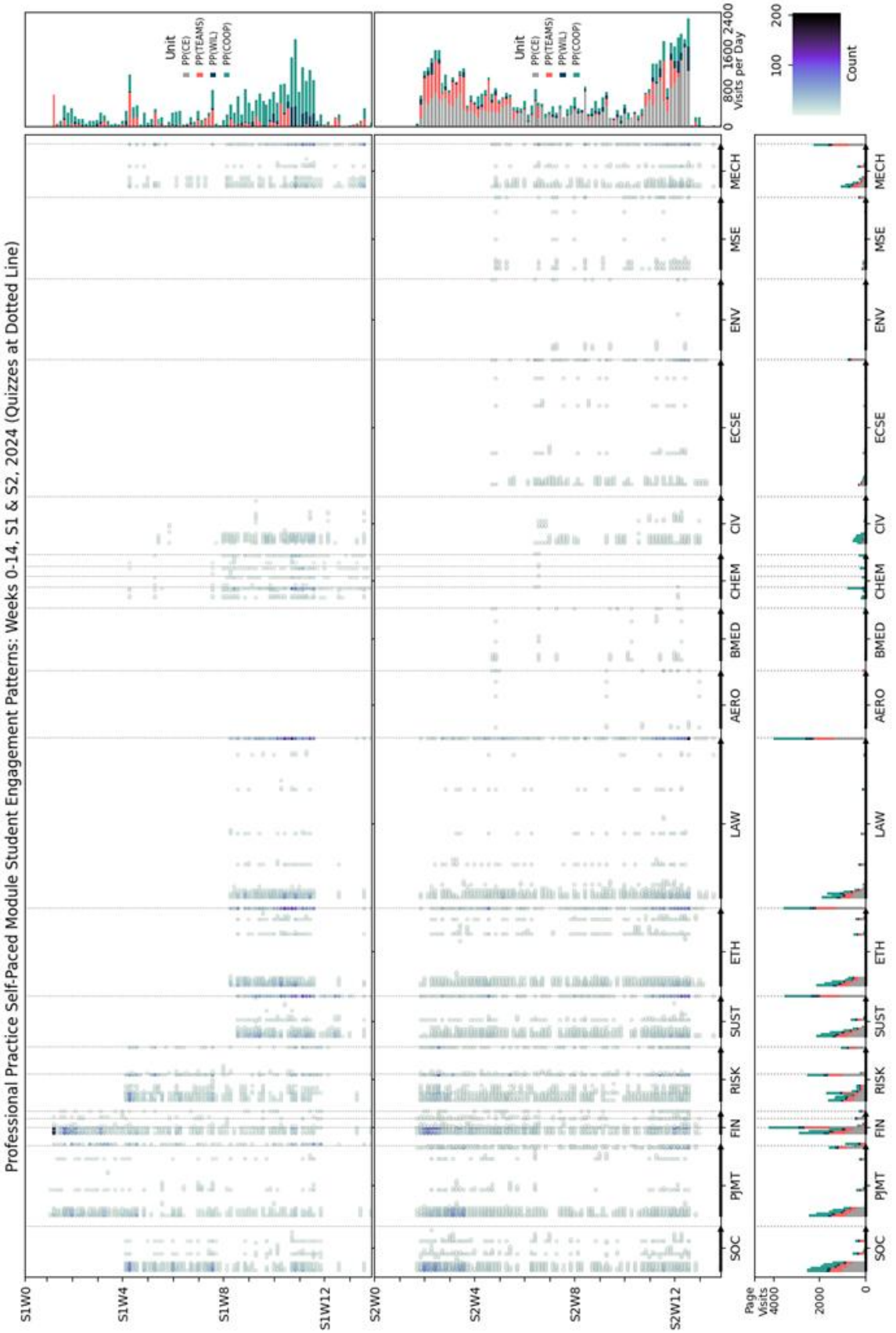


Figure 1: Joint grid visualization showing the trends between module page visits (x-axis) and visits per day (y-axis) with scatter plots. Marginal plots display univariate distributions: page visits per module (bottom) and daily visits (right), colour-coded by PP unit.

- This structure may contribute to a more noticeable decline in engagement as the semester progresses.
- Quizzes are attempted even if the content in the modules have not been viewed, especially at the end of the semester.
- Staggered release of the modules (as seen in S1) appears to have prompted more students to engage with the modules throughout the semester. This contrasts with S2, where all the common modules were available from the start of the semester.

Discipline-specific modules:

- Note: In S1, only Chemical, CIvil and Mechanical & Mechatronics modules were available.
  Generally these modules have been released later in the semester than the common set of modules, and they have lower engagement. Mechanical & Mechatronics has noticeably higher activity than the others.

Cohort differences

- All cohorts demonstrate heightened levels of engagement at the beginning and end of the semesters.
- Co-operative education professional practice, PP(COOP), demonstrates strong and consistent engagement with the suite of modules in S1.
- The curriculum-embedded professional practice, PP(CE), which only started in S2 appears to have a cohort that engaged with the modules most consistently throughout the semester.

Key Findings (From Clustering)

Shared diverse student engagement trajectories

An initial visual inspection of the engagement trajectories for the 2024 cohort of Professional Practice students, as shown in the figure, highlights similarities in broad patterns. The overall spread and shape of the data points suggest general consistency, regardless of whether students submitted the summative quizzes for each module. Engagement patterns are consistent among students who failed (F), achieved passing grades (P of high pass, HP) or did not submit quizzes (X). Most students who completed the online module quizzes passed the assessment. However, distinct differences in learner behaviour are evident between unit cohorts. Notably, while students from non-quiz-submitting cohorts show generally similar engagement patterns, the PP(COOP) cohort exhibits unique characteristics. The streak-like structure of the data indicates that engagement trajectories are diverse yet follow similar underlying patterns.

LESSONS LEARNED & CONTINUAL IMPROVEMENT

In conclusion, adopting a structured, iterative CDIO approach has proven essential for evolving instructional design in response to real student experiences and engagement patterns. By consistently reassessing student motivations during the **Conceive** phase, educators are given the opportunity to reflect on whether the learning modules remain relevant and meaningful. Gathering direct feedback from students and subject matter experts is expected to provide actionable insights that inform necessary design improvements, ensuring the learning experience aligns with the needs and expectations of the students.

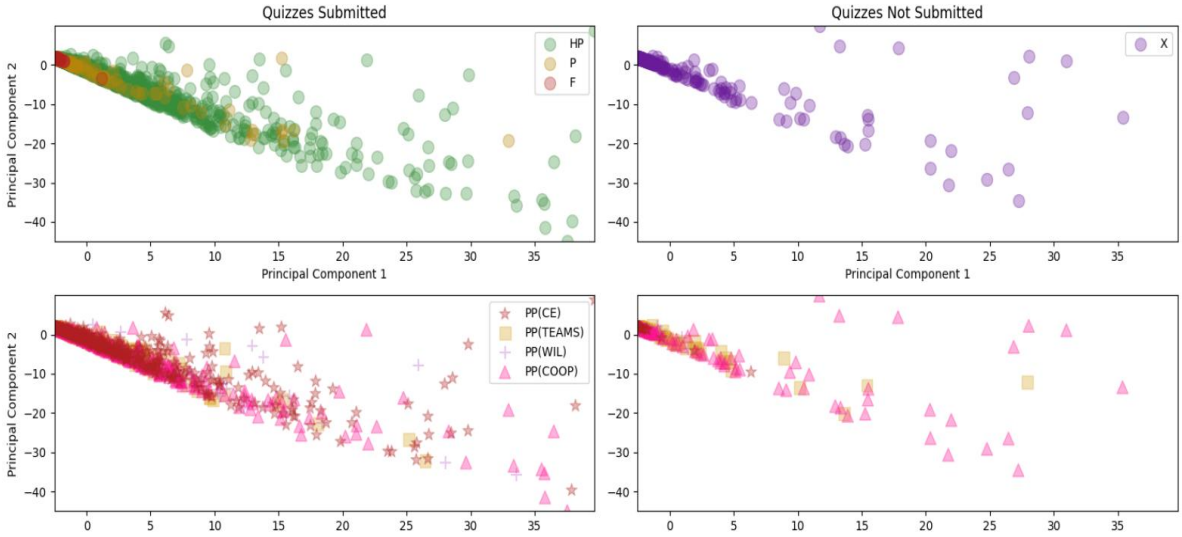


Figure 2: Principal Component Analysis (PCA) was applied to timestamp sequences of student engagement with module items. Each point represents a student's interaction with a module, revealing patterns about assessment submission (Quizzes submitted VS Quizzes not submitted columns) and relationships across the cohort vs whole of the Professional Practice cohort in subplot rows.

The **Design** phase has highlighted that even small refinements, such as experimenting with the progressive reveal of content, can positively influence student engagement behaviour. Additionally, structuring longer modules with intermittent quizzes, rather than relying on a single final assessment, helps maintain cognitive engagement and minimizes learner fatigue. This approach reinforces the importance of pacing and regular interaction in supporting sustained learning.

In the **Implement** phase, the inclusion of professional practice engagement features, such as peer discussions, has shown promise in promoting deeper learning and collaboration. These elements support students in connecting with the practical relevance of their learning and help cultivate a sense of community in self-paced environments. While these features have been beneficial, the impact could be further improved with more regular facilitator engagement and prompting, ensuring continuous interaction and encouragement for students to actively participate. This could further enhance both student engagement and understanding, particularly in independent learning settings.

Finally, the **Operate** phase ensures that the design process remains dynamic and responsive. By leveraging analytics to continuously evaluate the impact of changes on student engagement, instructional designers can refine and optimise the learning experience over time. This ongoing cycle of data-driven decision-making supports the continual enhancement of the course, ensuring that improvements are sustainable and aligned with student needs while working within existing constraints.

The iterative nature of this CDIO approach affirms the importance of being responsive to student feedback and engagement data, allowing for continual improvements that can enhance both learner outcomes and engagement in online self-paced, auto-graded modules. Ultimately, this reflective and adaptive process offers a robust framework for instructional design that drives long-term success and learner satisfaction.

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AI Usage Declaration

During the final editing phase, generative AI (ChatGPT) was employed to provide feedback on the tone, clarity, and overall flow of the writing. The author carefully reviewed the AI-generated suggestions, making adjustments to improve readability and coherence where appropriate. However, no text directly generated by the AI was substituted for the author's original content.

Authors of Educational Resources

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FROM SHARING TO SYNERGY: CULTIVATING INCLUSIVE EDUCATIONAL ENVIRONMENTS THROUGH EDI IN CDIO

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ABSTRACT

This paper is a product of the Monash Equity, Diversity, and Inclusion Sharing Circle (EDISC) and seeks to highlight alignments between the Conceive-Design-Implement- Operate (CDIO) framework and Equity, Diversity and Inclusion (EDI) concepts and provide inspiration for how to operationalise these. EDISC builds connections between education practitioners from across the Monash community who influence teaching practices in Monash courses, including those offered in the multiple disciplines and specialisations of the Faculty of Engineering. The shared mission of the group members producing this paper is to identify opportunities to influence and advocate for equitable practices and considerations during the conceive, design, implement and operate stages of learning experiences. By leveraging these synergies, the group aims to contribute towards the cultivation of environments that are diverse, equitable, and inclusive, and observe the results of these. As such, this group is well placed to advise on how this can be achieved through frameworks such as CDIO. This can influence better educational outcomes, fostering a holistic approach in CDIO that incorporates social and ethical dimensions alongside technical excellence. This paper highlights the opportunities for embedding EDI in the CDIO framework and philosophy, identified by members of our Sharing Circle.

KEYWORDS

Equity, Diversity and Inclusion (EDI), Universal Design for Learning (UDL), Accessibility, Standards: 1-12

INTRODUCTION

Inclusion and equity have emerged as pivotal concerns in engineering education, where diverse perspectives and equitable opportunities are crucial for cultivating innovative, ethical, and socially responsible engineers. The CDIO (Conceive- Design- Implement- Operate) framework, widely adopted for its emphasis on practical, real-world engineering education, provides a robust platform for addressing these challenges. This paper explores how the principles of inclusion and equity can be systematically embedded into the CDIO framework, ensuring that engineering curricula and practices are accessible and beneficial to all students, regardless of their backgrounds or circumstances. By integrating these values into the framework's processes and outcomes, this study aims to advance a more inclusive and equitable future in engineering education.

Alignment of CDIO with Equity, Diversity and Inclusion:

The CDIO syllabus aligns closely with the United Nations Educational, Scientific, and Cultural Organization (UNESCO) framework (Delors et al., 1996), particularly in its application to engineering education (Crawley et al., 2009). At its core, the CDIO Syllabus is divided into four categories, which correspond to UNESCO's four pillars of education, as shown in Table 1.

Table 1. Mapping CDIO to UNESCO

CDIO	UNESCO
Technical Knowledge and Reasoning	Learning to Know
Personal & Professional Skills & Attributes	Learning to Be
Teamwork and Communication	Learning to Live Together
Conceiving, Designing, Implementing and Operating Systems in the Enterprise and Societal Context	Learning to Do

The connection between the CDIO Syllabus and the UNESCO framework underscores the need for equity, diversity, and inclusion (EDI) to be core elements of the CDIO framework. Educational practitioners and decision-makers must apply EDI fluency for effective implementation. In line with CDIO Standard 10 (2010), programs should enhance faculty competence through integrated learning experiences (Standard 7), active and experiential learning (Standard 8), and student learning assessments (Standard 11). However, a review of 17 years of CDIO submissions (Meikleham et al., 2018) reveals that faculty development has been underrepresented in CDIO literature, highlighting a gap that needs to be addressed for more effective implementation.

CASE STUDY CONTEXT: EDI SHARING CIRCLE AT MONASH UNIVERSITY:

An example of applying these principles in practice is the EDI Sharing Circle (EDISC) at Monash University, ranked as the number one engineering school in Australia (THE, 2023 & 2024). The newly established EDISC initiative aims to foster partnerships with the Monash Engineering Equity, Diversity, and Inclusion (EDI) Faculty Committee and Faculty EDI academic representatives. There is enormous potential for educators in formal and informal positions of influence, where supported by senior leaders, to cultivate supportive cultures and drive change on equity matters (Jacobs et al., 2014), and the purpose of the Monash EDI Sharing Circle is exactly that. It exists to support members in their efforts to influence educators, curriculum, leaders and policy towards the implementation of positive and inclusive

educational practices that respect and celebrate diversity. The EDISC consists of Monash staff in advisory roles who influence educational practices within programs (courses or subjects), focusing on indirect practice. It is less about 'how can I be more inclusive' and more about 'how can I encourage inclusive practices in our courses/subjects'. Members of the sharing circle also recognise that the higher education sector is predicated upon a flawed belief in a meritocratic society (Stein & Andreotti, 2018) where in fact all peoples have constrained agency in their aspirations and outcomes (Polesel et al., 2017). As such, the EDI Sharing Circle seeks to strike a delicate balance between working with the structures and system of the higher education sector and problematising them.



Figure 30. Structure of discussion of EDI frameworks influencing Monash Engineering

EDI Frameworks

A variety of frameworks shape the practice of EDI principles (see Figure 1). Monash's engineering degrees are offered at campuses in both Malaysia and Australia. The Australian programs are accredited by Engineers Australia to the Stage 1 Competency Standard (Engineers Australia, 2019). As the peak body for engineering in Australia, Engineers Australia has outlined the following strategic priorities related to inclusion and diversity: **Creating Tomorrow's Engineers**: Enhance the diversity of the engineering profession to attract the best talent and retain top performers, **Provide a Professional Home for Life**: Celebrate individual differences that reflect the communities we serve, and **Be the Trusted Voice of the Profession**: Advocate for programs and support that foster a diverse engineering workforce.

The EA Diversity and Inclusion Positioning Statement (2022) defines a diverse workplace as one that values individual differences, reflecting community diversity. An inclusive workplace ensures fair treatment, equal access to opportunities, and full contribution to success, fostering a sense of belonging where every employee feels valued and heard. These principles align with the United Nations Sustainable Development Goals, UN SDGs, (2016, 2017), including Goals 4 (Quality Education), 5 (Gender Equality), 8 (Decent Work and Economic Growth), 10 (Reduced Inequalities), 16 (Peace, Justice, and Strong Institutions), and 17 (Partnerships for the Goals).

Advancing EDI Goals through EDI Sharing Circle

Under the Monash University EDI Framework (2021), there are aspirations to build an inclusive community. The Enabling and Evaluation Plan 2023-2024 outlines these goals, and these overarching principles must be translated into actionable steps for engineering educators. By aligning these principles with the strategic priorities of the UN SDGs, Engineers Australia, and Monash's strategic plan, the engineering faculty can take concrete steps to implement inclusive practices and foster an equitable learning environment. The Monash EDI

Sharing Circle (EDISC), aims to support faculty in advocating for and implementing inclusive practices in the curriculum. Through its collaborative structure, the Circle envisages empowering educators to integrate EDI principles, contributing to Monash's commitment to a diverse and inclusive engineering community. This paper represents the first step in empowering faculty and positioning the group to drive meaningful change as it develops.

METHODOLOGY

Mapping the CDIO Standards to the EDI Frameworks

While other frameworks exist, such as Higher Education Standards Framework (Threshold Standards) (TEQSA, 2021), this paper adopts the lens of inclusion and accessibility as outlined by Advance Higher Education (Advance HE), formerly known as the Higher Education Academy. Advance HE offers a globally recognised program for acknowledging contributions to higher education, with a standard that supports professional progression from Associate Fellow to Principal Fellow, reflecting various stages of experience in both academic and professional roles. Advance HE collaborates with 400 institutions globally (Figure 2) to promote institutional, staff, and student success, including some CDIO members. Through its global reach, Advance HE supports institutions foster diversity, inclusion, and equitable opportunities across varied cultural and institutional contexts.



Figure 2. Geographic comparison of global distribution CDIO collaborating institutions (CDIO Initiative, 2024) and Advance HE member institution.

By exploring the CDIO framework standards, the EDI Sharing Circle aims to identify opportunities to embed inclusion and accessibility, while addressing the benchmarks set by Advance HE (Hanesworth, 2019). The five domains of the Advance HE program standard (Curriculum Design, Curriculum Delivery, Assessment and Feedback, Learning Environments and Staff Engagement) were used in the structuring of the process, as shown in Table 2.

The mapping, summarised in Table 2, was a collaborative effort by the EDI Sharing Circle members, combining asynchronous work with regular online meetings. Drawing on their expertise in the Advance HE EDI standard, Universal Design for Learning (UDL), inclusive practices, programmatic assessment, constructive alignment, and other related guiding principles, they significantly contributed to guiding the mapping process. This collective knowledge is evident in the emerging themes, which integrate these diverse elements.

Table 2. Overview of mapping between Advance HE EDI Framework & CDIO Standards. Ticks (✓) show alignment between an element of the EDI Framework and a CDIO Standard.

		CDIO Standards											
Advance HE EDI framework (Hanesworth, 2019)		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Curriculum Design:	8 principles	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Curriculum Delivery:	8 principles	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Assessment & Feedback:	8 principles	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Learning Environments:	7 principles	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Staff Engagement:	8 principles	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Thematic Analysis

The analysis employs a two-pronged approach; an unsupervised machine learning clustering techniques to identify patterns and provide a quantitative basis for underlying themes, followed by qualitative insights from the EDI Sharing Circle to enrich the analysis with expert perspectives. This combined methodology helps identify patterns and connections between words and concepts in the data, making it easier to see how they are linked and interact with each other.

RESULTS AND DISCUSSION

By combining both computational and human perspectives, we aim to provide a multi-layered analysis of the patterns and relationships within the data. In this section, we first present results from computational clustering methods applied to our dataset, offering a data-driven approach to identify underlying patterns. We then turn to insights from human subject matter experts, whose expertise adds a qualitative layer to the analysis. The curious can find the documentation of the complete mapping located in the Appendix.

The computational analysis begins with the use of word embeddings, which serve as a key tool in mapping relationships within the data. Word embeddings, a type of natural language processing, detects patterns in text to extract meaning by learning from a collection of unlabelled sentences. The algorithm considers surrounding words for context, creating a numerical representation of each word as a high-dimensional vector (for example, 100-D), which is then used to train the model. We use t-distributed stochastic neighbor embeddings (t-SNE) (Van der Maaten and Hinton, 2008) to visualise and identify broad patterns in the results of our analysis.

This method consolidates complex, multi-dimensional data (like language sequences) into a two-dimensional graphical space, as shown in Figure 4. Each plotted point represents the mapping of one CDIO Standard element to the Advance HE EDI framework, with the same data points appearing in both subplots; CDIO standards-based designations on left and computationally detected themes on the right.

In Figure 4, we observe that the themes identified through computational analysis (described in Table 3) transcend the individual CDIO standards, revealing broader, interconnected patterns. This suggests that the equity, diversity, and inclusion themes span multiple

dimensions of the CDIO framework, offering a more holistic view of the data. These findings indicate that the computational approach has uncovered cross-cutting themes that may not be apparent when considering each standard separately.

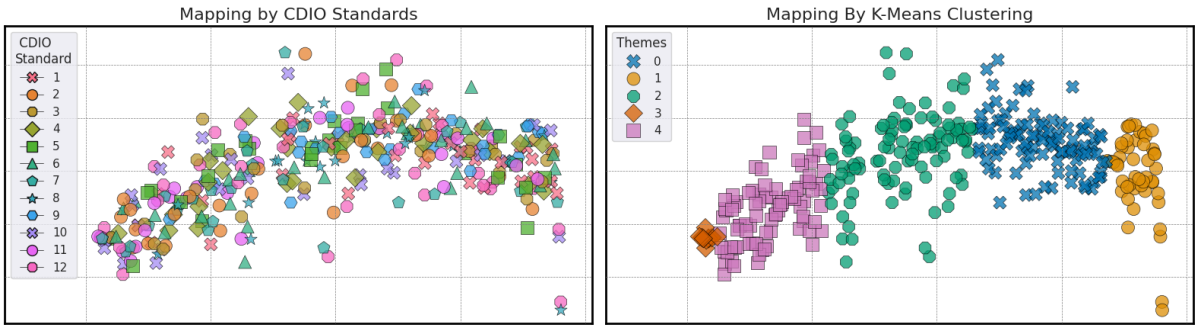


Figure 4. Note: The axes in this visualisation are defined through Principal Component Analysis (PCA), capturing the primary directions of variance in the data. While they reveal dominant patterns, they do not directly align with specific, easily interpretable meaning

Table 3. Themes extracted from unsupervised machine learning cluster analysis

Theme Number: Theme
0: Inclusivity → ['students', 'skills', 'learning', 'faculty', 'edi'] *This cluster highlights EDI (Equity, Diversity, Inclusion) alongside foundational educational elements, suggesting a focus on inclusive learning environments.*
1: **Curriculum Relevance** → ['edi', 'students', 'relevant', 'perspectives', 'disciplinary', 'faculty', 'curriculum', 'needs'] *Combines EDI, disciplinary relevance, and curriculum responsiveness to diverse perspectives and needs.*
2: Equitable Assessment → ['students', 'learning', 'assessment', 'staff', 'edi'] *Assessment and EDI together point towards fairness and inclusivity in evaluating student learning.*
3: Learning Design → ['outcomes', 'assessment', 'learning', 'design'] *A cluster pointing to structured and intentional learning experience design.*
4: Competency Mapping → ['assessment', 'students', 'learning', 'outcomes', 'engineering', 'skills', 'curriculum'] *This reflects an emphasis on aligning assessment with learning outcomes and engineering competencies.*

This alignment is not surprising, as effective frameworks often share foundational principles grounded in inclusivity, adaptability, and student-centred approaches. Such overlap reflects the universal importance of key educational priorities, such as fostering equitable learning environments, ensuring accessibility, and promoting cohesive programmatic structures. The findings reinforce the notion that well-designed frameworks naturally converge around common goals, which practitioners can leverage to create more integrated and impactful educational practices. To further explore these findings, it is useful to compare the computational theme identification with the human insights from the EDI Sharing Circle. While the computational analysis reveals broad, interconnected patterns across the CDIO framework, the human analysis highlights specific, actionable practices for fostering inclusion and agency, as specified in Table 3.

The themes in Table 4 emphasise the importance of co-design and agency, with student feedback being central to course improvement and fostering motivation. Scaffolding supports student transition into higher education through structured guidance, while diversity and accessibility in the curriculum are crucial for effective learning outcomes and reducing biases.

Additionally, faculty competence in inclusion is essential for enhancing student success and creating an inclusive learning environment.

Table 4. Themes identified by members of the EDI Sharing Group during the mapping of Advance HE EDI framework against CDIO Standards

Themes	Description	Examples of practice
1: Agency > Co-design	Emphasising the value of student and stakeholder feedback is key. This theme recurs across Map Staff Engagement and Map Assessment and Feedback mapping. Integrated/circular feedback and co-design practices enable meaningful evaluation of the assessment, course, and workspaces, and incorporating it into course cycles enhances student agency. Focus on enacting feedback, not just collecting it ('listening'). Two-way communication is important, and student's voice is critical for accurately evaluating programs. Co-design fosters student agency, motivation and engagement, and supports more personalised learning in traditionally fixed pathways, and strengthens inclusion and belonging through real-world relevance.	Expanding networks to include representation, advocacy and allies (disability, women/LGTBIQ in engineering, and culturally diverse engineering firms) Student focus groups within units and courses to inform all aspects of the CDIO standards. Students co-creating the curriculum.
2: Scaffolding	Effective scaffolding supports students transitioning from school (or non-traditional backgrounds) to higher education by guiding them through disciplinary knowledge and skill development. Implementing feedback cycles and iterative approaches, especially in early stages, ensures continuous growth.	Using near-peer mentoring to bridge the gap between educators and beginner students.
3A: A diverse student cohort yields better learning outcomes and artefacts	To be effective engineers who can contribute to society's future needs, students must design for a wide range of human experiences and consider diverse perspectives. Engaging with peers from diverse backgrounds is essential for this. Failing to do so increases the risk of creating artefacts that are unfit for purpose and perpetuate inequity, discrimination, and bias. Students' fresh perspective, free from prior expertise or bias in design standards, makes them well-positioned to identify EDI issues within systems.	Students designing digital technology for in-home care must access the experiences of those with disabilities, carers, families, and support workers. An accessible learning environment ensures that students with disabilities or caregiving duties can contribute meaningfully, enriching both their learning and that of their peers.
3B: Accessibility of curriculum, learning spaces, etc. essential for individual student success	Incorporating accessibility practices, cultural safety, and equity throughout the curriculum and teaching practices is vital to ensure student success. Integrating these practices ensures students acquire the necessary skills and knowledge, while a lack of accessibility hinders their potential.	Students reviewing a engineering design drawing/model are provided with accessible materials, considering diverse sensory and neurodevelopmental needs (e.g., vision and auditory differences, dyslexia, ADHD).
4: Faculty competence in implementing inclusion into CDIO Framework to improve student experience and learning outcome	While faculty are recognized as subject matter experts, their qualifications often lack specific training in inclusion and equity beyond mandatory compliance. Demystifying inclusive practices and building confidence in faculty is essential to maximise student success, belonging, and well-being. Institutions must integrate inclusion and equity into faculty development, fostering both teaching competence and an inclusive learning environment. Additionally, recognizing system and structural issues that hinder faculty diversity is crucial in addressing barriers to diverse hiring practices.	Faculty development should include training on universal design for learning, unconscious bias, and equitable participation, while institutions should implement diverse hiring panels and mentorship programs to support underrepresented groups in academia.

CONCLUSION

This paper explores how the CDIO framework can be enhanced with principles of equity, diversity, and inclusion (EDI), using the EDI Sharing Circle as a case study. Our analysis shows that EDI themes, such as co-design, scaffolding, and faculty competence, span multiple CDIO standards, highlighting the interconnectedness of these concepts. The integration of computational analysis and expert insights demonstrates that embedding EDI within the CDIO framework promotes more inclusive, student-centred educational practices. This approach offers a practical pathway for engineering educators to foster more equitable and accessible learning environments..

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AI Usage Declaration

During the final editing phase, generative AI (ChatGPT) was employed to provide feedback on the tone, clarity, and overall flow of the writing. The author carefully reviewed the AI-generated suggestions, making adjustments to improve readability and coherence where appropriate. However, no text directly generated by the AI was substituted for the author's original content.

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APPENDIX: PART 1A (OF 5) CURRICULUM DESIGN
MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (1-3)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 1: Context	Standard 2: Learning Objectives	Standard 3: Integrated Curriculum
Accessibility of and flexibility in programmes of study that allow students to input on their learning pathways and experiences. (1/8)	Connectivity: The CDIO context encourages student input, with a variety of project choices offering flexibility. --- Tip: Evaluation groups should consider the diverse student body, recognising that some may struggle to engage in engineering processes. While some students may have prior experience, others may find CDIO less accessible. --- Example: CDIO provides the context for engineering education, but each student's pathway within that framework can be unique, as long as the overall structure remains consistent.	Connectivity: Internal and external groups regularly review and revise program learning outcomes and/or program goals based on changes in student and stakeholder needs. --- Tip: Ensure multiple learning pathways can be used to achieve learning outcomes. --- Example: Learning outcomes include creativity and critical thinking, nurtured through a student-centered approach. As long as technical and disciplinary knowledge is covered, students can choose their topic and assessment method.	Connectivity: Internal and external stakeholders regularly review the integrated curriculum; they could consider the accessibility and flexibility of the integrated curriculum. --- Tip: Allow students flexibility in the level/rate at which their learning experiences lead to the acquisition of personal and interpersonal skills. --- Example: Some students have strengths in product, process or system skills but lack interpersonal skills, while others' strengths may lie in interpersonal skills and need to work on disciplinary knowledge.
Accessibility of learning outcomes and/or competence standards. (2/8)	Connectivity: The CDIO program inherently increases the accessibility of learning outcomes by encouraging effort and persistence because it mimics an authentic engineering design experience --- Tip/Example: Optimise the relative emphasis of task 'challenge and support' to ensure sustained effort. Students are offered scaffolds where required and freedom to build confidence in their capability.	Connectivity: The CDIO standards emphasise the need to regularly review learning outcomes based on stakeholder needs, which is directly linked to accessibility requirements and that learning outcomes are clearly linked to the profession's core competencies. --- Tip: Check that learning outcomes are free from unnecessary barriers. --- Example: The review includes checking that learning outcomes do not disadvantage individuals or groups.	Connectivity: The integrated curriculum explicitly maps specific learning outcomes to courses and co-curricular activities. This makes learning goals clear and accessible. --- Tip: Prioritise student feedback on the accessibility of learning outcomes and their connections to learning experiences. --- Example: Students should report they are clear about their learning goals across the program and find them meaningful.
Considerations of EDI in learning outcomes and/or competence standards. (3/8)	Connectivity: Integrating EDI principles into learning outcomes and competency standards ensures that engineering education promotes the development of sustainable products, processes, systems, and services that are inclusive and equitable, encouraging diverse perspectives and solutions for addressing global challenges. --- Tip: Demonstrate how the CDIO process and EDI principles are inherently connected to increase buy-in. --- Example: The CDIO adoption in a course is aligned with explicit standards and outcomes that reflect core EDI practices.	Connectivity: These are inherently connected in that the learning outcomes are the centre of the program and the most critical place to situate EDI principles. --- Tip: Create a spreadsheet aligning the learning outcomes to the Advance HE EDI framework to identify areas for improvement. --- Example: EDI considerations involve ensuring that learning outcomes include the ability to work effectively in diverse teams and understand the impact of engineering solutions on different communities.	Connectivity: Integrating EDI principles into learning outcomes and core competencies ensures an inclusive curriculum that develops both interpersonal and disciplinary skills for an internationalised society. --- Tip: Embed EDI concepts in all levels of learning outcomes to ensure a more integrated alignment. --- Example: The curriculum offers opportunities for interpersonal and disciplinary skill development through an ePortfolio, capturing evidence of analysing diverse perspectives and designing inclusive engineering solutions for various contexts.
Tackling of the impact of own identity beliefs, cultural assumptions and unconscious biases as part of the design process. (4/8)	Connectivity: Engineering programs that challenge personal assumptions and biases as part of the CDIO process help students Conceive–Design–Implement–Operate complex, sustainable products, processes, systems, and services in team-based environments. --- Tip: Students may not recognise how their cultural beliefs and assumptions differ from others unless they are exposed to alternative perspectives. --- Example:A reflective framework with prompting questions to critically examine unconscious bias and cultural sensitivity, integrated into each phase of the CDIO program.	Connectivity: The CDIO syllabus and program learning outcomes should reflect the importance of personal and interpersonal skills alongside technical knowledge, which aligns with the need to address assumptions and biases in the design process. --- Tip: Unpacking assumptions and biases do not have to be explicit in the program learning outcome. --- Example: Feature critical reflection practices, personal goal setting and effective teamwork and communication as part of learning outcomes	Connectivity: Combining these standards creates a curriculum that requires students to reflect on their own biases and how these might impact their engineering decisions. This can lead to more sustainable and culturally sensitive design practices. --- Tip: Front-load /scaffold critical reflection on bias as a core component of personal and interpersonal skills. --- Example: Using ePortfolio and programmatic assessment allows curriculum designers to systematically embed critical reflection on biases, increasing in complexity throughout the course. This approach also allows skills within the discipline to develop progressively over time.
Opportunities for students to co-create their curricula. (5/8)	Connectivity: Co-creation of the curriculum allows for diverse voices in the realisation of the CDIO format and increases student agency and motivation. --- Tip: Co-creating the curriculum allows students to develop negotiation skills. --- Example: A mechanical engineering program that allows students to co-design a semester-long project focused on sustainable product development.	Connectivity: Allowing students to co-create learning outcomes helps them understand the bigger picture of their program and its design and alignment. --- Tip: While some learning outcomes are fixed by institutional and industry policies, those related to specific classes or weeks are more flexible for co-creation. --- Example: Show students how a subject learning outcome aligns with the program learning outcome, and have them co-create learning outcomes for the next class.	Connectivity: Co-creating the curriculum allows students to recognise areas for improvement in their personal, interpersonal, and professional skills and product, process, system, and service building skills. --- Tip/Example: Have students begin the second year using a self-audit of their skill sets and areas for improvement, then co-create their assessment to target the cohort's common areas.
Course content that facilitates exploration of themes of equality, diversity, inclusivity and cultural relativity. (6/8)	Connectivity: CDIO is part of the cultural environment in which skills and knowledge are formed. A cultural environment that is holistic, responsible and considers broader societal impacts. --- Tip: Embedding themes of equality in a process ensures a more systematic coverage. --- Example: Have students consider the development of a new public transportation system that considers inclusive transport design from conception through to operation.	Connectivity: Themes of equality, diversity, inclusivity, and cultural relativity can be embedded within the program learning outcomes to develop well-rounded professionals capable of navigating complex social contexts while applying technical skills. --- Tip: Equity themes align with ethics and serve as a strong starting point for these outcomes. --- Example: Students can evaluate how socioeconomic factors impact design requirements or describe diverse user needs in product design.	Connectivity: When students explore themes of equality, they develop key interpersonal skills, such as empathy, cross-cultural communication, and collaborative problem-solving. --- Tip: Equity themes can be unpacked both within the project focus and also in the group communication style and the scaffolding of teamwork skills. --- Example: Students could collaboratively develop a support-based app for unhoused people from different cultural backgrounds and ability levels.
Course content that covers multiple perspectives, theoretical standpoints and contributions by people from multiple cultures and backgrounds. (7/8)	Connectivity: Perspectives and theories influence every stage of the CDIO model, requiring diverse contributions for a holistic application in engineering education. --- Tip: Integrating multiple perspectives can cause friction when standpoints differ, so ensure faculty are prepared with safe mediation strategies. --- Example: When implementing or reevaluating the CDIO model across a program, elicit and enact feedback from stakeholders from multiple cultures and backgrounds with multiple perspectives.	Connectivity: The most impactful area for integrating multiple perspectives is in the learning outcomes, as they shape all learning across a program. This becomes challenging if the outcomes are developed with a singular cultural or theoretical bias. --- Tip: If your work area lacks diversity, seek feedback from third-space professionals such as educational designers, academic skills advisers, and equity and inclusion consultants. --- Example: During a program or subject review, consult with people from various roles, cultures, and theoretical perspectives.	Connectivity: Robust personal and interpersonal skills overwhelmingly require knowledge and acceptance of diverse perspectives and theoretical standpoints. --- Tip: Eliciting and enacting multiple perspectives while creating the integrated curriculum reduces potential weaknesses across the program and highlights areas for further development. --- Example: Identify the perspectives available within the program curriculum development team and, where there are blind spots, seek ways to improve the diversity of those represented in the integrated curriculum design group.
Incorporation of the embedding of EDI in the curriculum in classroom observation and peer review activities. (8/8)	Connectivity: CDIO prioritises team-based learning, with observation and peer review as integral components. Incorporating EDI into these tasks ensures the curriculum is accountable for EDI integration. --- Tip/Example: Map observation, peer review, and other essential personal and interpersonal skills within the CDIO syllabus to identify where they occur across a program. When focusing on teamwork in observation and peer review, include criteria that address equity principles to ensure learning outcomes do not disadvantage any individuals or groups.	Connectivity: Integrating EDI themes into Learning Outcomes (LOs) is essential for meaningful impact. Evaluating the teaching of EDI within those LOs ensures effective coverage. Peer review and class observations are effective mechanisms for this. --- Tip/Example: When planning peer reviews, unpack EDI themes in the learning outcomes and consider how students can demonstrate this. This helps identify what to look for in educator practices that support EDI. Pairing educators for peer review can also bring diverse perspectives to uncover elements they may have missed.	Connectivity: By incorporating EDI principles into peer learning systematically across a program, educators gain exposure to different viewpoints and experiences. This supports the development of better integrated technical engineering skills and interpersonal competencies. --- Tip/ Example: Develop a program-wide observation rubric that prompts reviewers to analyse the equity practices present in their educator colleagues' assessment tasks.

APPENDIX: PART 1B (OF 5) CURRICULUM DESIGN
MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (4-6)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 4: Introduction to Engineering	Standard 5: Design-Implement Experiences	Standard 6: Engineering Learning Workspaces
Accessibility of and flexibility in programmes of study that allow students to input on their learning pathways and experiences. (1/8)	Connectivity : The course incorporates "personal and interpersonal knowledge, skills, and attitudes" in the program, offering flexibility as these evolve with each new cohort. --- Tip: Build flexibility in the Intro to Engineering course, allowing students to influence learning pathways and experiences. --- Example: While the educator selects the core disciplines to be covered, students choose from various applications to explore from those disciplines.	Connectivity: Design-implement (D-I) experiences progress in complexity, offering students input on their learning pathways and experiences. --- Tip: Seek feedback from students with diverse experiences on the flexibility and input they felt they had in shaping their learning pathways within D-I experiences. --- Example: Educators collaborate with students to design challenges that are motivating and facilitative for them.	Connectivity : Students are expected to have input and 'directly engage in their own learning' according to Standard 6. --- Tip: Social learning is emphasised in this standard, so it is important to foster interdependence and collective learning. --- Example: From UDL - "Construct communities of students engaged in common interests or activities or who identify in similar ways."
Accessibility of learning outcomes and/or competence standards. (2/8)	Connectivity: The introductory course is well-suited to making the competence standards accessible by starting with simple design exercises preparing students for more advanced engineering experiences. It sustains effort by drawing on personal and interpersonal knowledge/skills/attitudes. --- Tip: Educators and students can work together to define what competence looks like in Engineering to ensure students have buy-in and are clear on their learning goals. --- Example: The educator might ask students to share their ideas of what is needed in Engineering: what makes a competent engineer? What perspectives do they bring to the field?	Connectivity: Design-implement experiences are structured to promote early success, with increasing levels of complexity that make learning outcomes and competency standards accessible. --- Tip: Emphasise real-world contexts and encourage students to explore personal, professional, and career interests to connect with learning outcomes.. --- Example: Include reflective practice in the design-implement experience, allowing students to examine what matters to them and ensure they are invested in their work.	Connectivity: This standard recognises that "competencies are best developed in workspaces that are student-centred, user-friendly, accessible, and interactive." --- Tip: Ensure students are involved in reviews and listened to, with action taken if they report any barriers to achieving learning outcomes due to workspace flexibility/constraints. --- Example: Students report they feel the workspaces support hands-on skills and activities but do not have easy access to tutors for guidance.
Considerations of EDI in learning outcomes and/or competence standards. (3/8)	Connectivity: Consideration of EDI practice in the introductory course learning outcomes emphasises the importance of creating sustainable and inclusive engineering solutions that benefit diverse communities. --- Tip: Introductory students, with their fresh perspective, can identify gaps in EDI practice in engineering designs that experts may overlook. --- Example:In the introductory course, have students reevaluate a historical engineering design, such as public bathroom spaces, to assess its alignment with EDI practices.	Connectivity: Aligning the design-implement experiences to EDI-themed learning outcomes helps students develop inclusive engineering designs that address diverse user needs. --- Tip: Use the campus as a real-world setting for design-implement experiences, encouraging students to design systems and products that enhance inclusion in their environment. --- Example: Create two design-implement experiences that build on disciplinary knowledge and EDI principles. The first could involve designing a simple, accessible ramp system, and the second, more advanced experience, could focus on designing an adaptive public transport entrance. These experiences progressively deepen students' understanding of user requirements across systems.	Connectivity: This relationship is important because it ensures that all students, regardless of their background or abilities, have equal opportunities to develop essential engineering skills and knowledge through hands-on experiences and digital tools. --- Tip: Leverage your institution's framework for inclusive practice to highlight issues in digital and physical learning spaces. --- Example: When creating program learning outcomes, EDI themes can reveal potential disadvantages in both physical and virtual engineering learning spaces by considering whether all students have equal opportunities to achieve the stated outcomes.
Tackling of the impact of own identity beliefs, cultural assumptions and unconscious biases as part of the design process. (4/8)	Connectivity: Having students critically reflect on bias during the design process helps them become more effective problem-solvers and team members in the introductory course. --- Tip: Assume students have little capacity to reflect on bias, so they all learn the same skills over time without anyone being disadvantaged due to a lack of prior knowledge. --- Example: Begin with an anonymous diagnostic survey in the introductory course, asking students to consider their own identity and beliefs, then build towards critical reflection on bias and assumptions.	Connectivity: Creating design-implement experiences that encourage students to unpack their own biases is a comprehensive approach to design that considers both technical skills and cultural competence. --- Tip: When assumptions are clear to the educators, you can prompt the students with questions like 'Why do you know that?', 'Why do you hold that as true?' and 'Could there be other possibilities?' --- Example: As students work through the design-implement process, they are required to document how they are addressing potential biases and incorporating cultural considerations into their engineering solutions.	Connectivity: Personal biases and cultural assumptions can affect the design of learning environments, limiting their effectiveness for diverse student populations. --- Tip: Questioning frameworks help identify unconscious biases. --- Example: Ask questions to uncover biases when developing the curriculum: What assumptions are we making about people's abilities in online content? Are we assuming everyone can differentiate colors equally? What assumptions are we making when designing lab spaces, such as a specific height standard for workbenches in educational spaces?
Opportunities for students to co-create their curricula. (5/8)	Connectivity: Co-creating the introductory course allows students to voice their needs early in the program. --- Tip: Since students may struggle to fully articulate their needs, a set of reflective questions can help them express these needs. --- Example: Have students complete initial problem-solving tasks and ask evaluative questions afterward. Use their feedback to create follow-up tasks that address the ideas raised.	Connectivity: Students can co-create their advanced design-implement experience to target their interests and needs. --- Tip: Students will need to experience something before they can form opinions and offer their voice, so this is best completed for the second design-implement experience. --- Example: Student teams create their own project timelines and deliverables and develop presentation formats that best suit their projects.	Connectivity: The physical and digital learning spaces allow opportunities for real-world exploration of equity themes. --- Tip: Integrate an evaluation of the equity considerations present (or not present) in the digital and physical workspaces into the program. Highlight quality design practices along with unsatisfactory practices. --- Example: Have students analyse their digital workspace and its adherence to accessibility principles.
Course content that facilitates exploration of themes of equality, diversity, inclusivity and cultural relativity. (6/8)	Connectivity: Embedding equity themes into the introductory course prioritises equity from the outset and develops students who can design products, processes, systems, and services that better serve all members of society. --- Tip: In introductory projects, have students visit the client community to connect with them as people rather than as a concept. --- Example: A project developing a water filtration system for communities with limited resources, where students learn fundamental engineering design principles while considering how community challenges impact sustainability.	Connectivity: Design-implement experiences lay the foundation for understanding the ethical and sustainability aspects of engineering. Immersing students in equity themes enhances their skills in these areas. --- Tip: Ensure evaluation is present in the design-implement experience to assess students' understanding of the equity themes in the project. --- Example: Create a design-implement experience for a hearing-impaired client, then have students analyze which aspects of the design would benefit all clients.	Connectivity: The physical and digital learning spaces allow opportunities for real-world exploration of equity themes. --- Tip: Integrate an evaluation of the equity considerations present (or not present) in the digital and physical workspaces into the program. Highlight quality design practices along with unsatisfactory practices. --- Example: Have students analyse their digital workspace and its adherence to accessibility principles.
Course content that covers multiple perspectives, theoretical standpoints and contributions by people from multiple cultures and backgrounds. (7/8)	Connectivity: Highlighting how different cultures and people approach problem-solving and design in the introductory course broadens students' understanding and prepares them for the global and collaborative nature of modern Engineering. --- Tip: Create a safe space for discussion by presenting a scenario with differing approaches and having students analyse potential conflicts. This encourages students to consider perspectives beyond their own. --- Example: .Showcase contributions from multiple perspectives by exploring the history of Engineering and how it has evolved to become more inclusive of diverse practices.	Connectivity: Faculty can encourage students to consider how cultural, social, and economic contexts influence the design and implementation of a product, process, or system in design-implement projects. --- Tip: Students do not always innately know how to engage respectfully when discussing multiple perspectives. Explicitly teach and offer guidelines for interpersonal skills before engaging students in discussions eliciting their own diverse perspectives. --- Example: Form diverse student groups to bring multiple perspectives to the table, enhancing creativity and innovation in the design process. With proper scaffolding, students can learn to appreciate and integrate different viewpoints.	Connectivity: The physical and digital learning infrastructure provides a practical space for students to explore how multiple perspectives, or the absence of them, impact the design of these spaces. This hands-on approach demonstrates how engineering affects people from diverse cultures and backgrounds. --- Tip: To ensure multiple perspectives are considered, it's important to evaluate who is involved in decision-making. --- Example: Have students analyse the design of physical and digital workspaces to identify which perspectives were prioritized and uncover representation gaps based on missing features.
Incorporation of the embedding of EDI in the curriculum in classroom observation and peer review activities. (8/8)	Connectivity: EDI concepts are simplified in introductory subjects to match student readiness. A review by another educator ensures the concepts are appropriately pitched. --- Tip/Example: Students from secondary education may be familiar with some EDI concepts but not within the Engineering context, so additional scaffolding should be considered during peer review.	Connectivity: Design-implement experiences benefit from peer review at the Conceive stage, where educators receive support in helping students explore all available options. EDI theming in the review emphasises embedding equity practices into engineering design. --- Tip: In peer review, reflective questions that challenge assumptions and biases in engineering design are highly effective in helping educators integrate EDI themes. --- Example: In groups, students design a campus navigation app. Peer review can focus on how educators have scaffolded the design, including accessibility, language inclusivity, and clarity of iconography.	Connectivity: When observing classrooms through an EDI lens, students can evaluate how well the physical and digital environments support diverse learning needs and ensure equitable access to hands-on engineering experiences. --- Tip: When analysing these spaces, consider both innovative possibilities and practical limitations, such as budget, and discuss the tensions between them. --- Example: Observational activities can assess how physical and digital spaces might hinder learning and identify improvements. For example, students with sensory sensitivities may struggle with bright neon lighting in labs, and educators can discuss possible alternatives.

APPENDIX: PART 1C (OF 5) CURRICULUM DESIGN
MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (7-9)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 7: Integrated Learning Experiences	Standard 8: Active Learning	Standard 9: Enhancement of Faculty Competence
Accessibility of and flexibility in programmes of study that allow students to input on their learning pathways and experiences. (1/8)	Connectivity: Integrated learning experiences draw on problem-based learning, which supports student input into their learning pathways and experiences. --- Tip: Ensure pedagogical approaches allow for self-regulated learning. --- Example: Students are supported and encouraged to have input into planning/goal setting, monitoring their progress and self-assessing.	Connectivity: Active learning engages students in constructing their knowledge, allowing input into their learning experience. --- Tip: Ensure active sessions or learning moments welcome interests and identities and support multiple means of engagement. --- Example: Provide flexibility for students to respond, such as using online whiteboards for classroom discussions.	Connectivity: Faculty are expected to be proficient in disciplinary knowledge and a range of skills, including personal, interpersonal, product, process, system, and service-building. This includes evaluating their ability to establish constructive relationships with diverse students and foster their learning. --- Tip: Develop faculty competence in acknowledging their power dynamic with students and encourage them to share that power to promote student agency and improve understanding. --- Example: Staff undergo training that emphasises that they are not the holders of all knowledge and that they can continue learning alongside their students.
Accessibility of learning outcomes and/or competence standards. (2/8)	Connectivity: This standard acknowledges that the learning outcomes can only be realised if disciplinary knowledge, personal/interpersonal skills and product, process, system, and service-building skills are developed simultaneously. It places importance on faculty as role models. --- Tip: Faculty should engage in critically reflecting on what they are modelling. --- Example: A staff member who models always knowing the correct answer might send a message to students that they, too, should always have the answers and if they do not, they might feel they will never reach competency in the profession.	Connectivity: Active learning fosters educational literacy in students and promotes collective and collaborative learning, helping students understand interdependence and see the value in supporting one another. This can improve accessibility to learning outcomes for all. --- Tip: Co-create active learning agreements in class that foster collaboration where students support and rely on each other. --- Example: In the first class, the educator facilitates the agreement and helps students connect and share their perspectives.	Connectivity: This standard recognises the need for faculty to keep up with change, be role models, and produce competent engineers in today's world. This means keeping up with the pace of technological change and social change. --- Tip: Professional development should include understanding social change so that outdated personal and interpersonal skills do not undermine optimal outcomes for diverse student populations. --- Example: EDI training to ensure faculty are comfortable with current understandings of gender identity, sexuality, and the need for social justice for historically oppressed and marginalised groups.
Considerations of EDI in learning outcomes and/or competence standards. (3/8)	Connectivity: Integrating EDI practices into learning outcomes creates an inherently integrated learning experience by merging disciplinary skills, professional skills and diverse perspectives, leading to more authentic and responsible experiences. --- Tip: Embedding EDI principles in program and subject learning outcomes informs integrated learning experiences. --- Example: Learning outcome: "Design inclusive engineering solutions that demonstrate technical competence and social responsibility." Activity: Students redesign a common household appliance to be more inclusive and accessible for consumers with rheumatoid arthritis.	Connectivity: EDI practice in learning outcomes, aligned with active learning tasks, naturally incorporates real-world engineering challenges. --- Tip: Students should understand that inclusive design affects both social awareness and the technical accuracy of their solutions. --- Example: Learning outcome: "Explain diverse physiological variations and their impact on medical device design". Active learning designer: Have students collaboratively develop data collection methods that respectfully gather relevant medical information.	Connectivity: Integrating EDI into learning outcomes creates a positive feedback loop. As faculty build competence in both technical and EDI areas, they foster a more inclusive environment and better prepare students to design inclusive engineering solutions. --- Tip: Emphasising engineering practice and stakeholder benefits upfront may increase buy-in from hesitant staff. --- Example: A faculty development series with learning outcomes that combine engineering practice and EDI principles—for instance, exploring how robotic design impacts diverse user groups or how watershed management can support equitable water access different socioeconomic groups.
Tackling of the impact of own identity beliefs, cultural assumptions and unconscious biases as part of the design process. (4/8)	Connectivity: Personal awareness and reflexivity directly impact the effectiveness and quality of integrated learning experiences. Educators can create more inclusive and comprehensive integrated learning experiences that better serve students and future stakeholders by acknowledging identity, beliefs, cultural assumptions, and unconscious biases. --- Tip: Create a rubric or guiding questions for peer review of teaching sessions designed to unpack unconscious bias. --- Example: What cultural and social assumptions are made when selecting student groups? What is the educator's expectation of students, and how much has been explicitly stated? What prior technical knowledge is assumed within the integrated learning experience, and do all students share it?	Connectivity: When educators understand their own cultural assumptions, they can design more inclusive and equitable active learning experiences that resonate with diverse student populations. --- Tip: Sensing internal resistance to change can be a good indicator of an internal bias. --- Example: An educator may feel resistance when being encouraged to design active learning experiences. Upon reflection, this could be due to their prior education being heavily theoretical, and this bias might disadvantage students from backgrounds where practical, community-based problem-solving is valued.	Connectivity: Educator self-awareness helps to create an inclusive curriculum, as well as helping educators identify potential gaps in their disciplinary knowledge or experience. --- Tip: Employing educators with a diversity of experience will help to showcase these potential biases in the curriculum. --- Example: Through self-reflection, an educator might realise their unconscious bias towards certain technological solutions based on most of their disciplinary experiences being in developed urban areas. This bias might lead them to unconsciously dismiss or undervalue traditional or Indigenous engineering solutions that could be more appropriate in different cultural contexts.
Opportunities for students to co-create their curricula. (5/8)	Connectivity When students shape their learning, they are more likely to connect disciplinary knowledge and skills with real-world applications and personal interests. --- Tip: Reignite waning engagement in online classes by offering students a choice of resources and activities. --- Example: Students could vote on and select non-academic sources to analyse alongside academic ones, fostering connections to the real world and developing integrated disciplinary skills.	Connectivity: When students co-create the curriculum and engage in active learning, they become designers of their own education rather than passive recipients. --- Tip: While learning styles have been repeatedly debunked, offering students a choice in learning activities can increase motivation and engagement (though not necessarily outcomes). --- Example: Co-create with students three activities aligned with the same learning outcome that use different skills, for example, one that focuses on written research, one on discussion and one on visual conceptualisation. Allow students to choose their preferred activity and discuss their experiences as a class.	Connectivity: Faculty competence impacts co-creation heavily in that faculty need support to manage and facilitate the unique range of student learning pathways that could be created. --- Tip: Co-creation of curriculum could expand the disciplinary context, but care needs to be taken so that it does not narrow the required disciplinary coverage. --- Example: Assign disciplinary skills/concept 'champions' within the faculty so educators venturing outside their strengths through co-creation can be supported by colleagues.
Course content that facilitates exploration of themes of equality, diversity, inclusivity and cultural relativity. (6/8)	Connectivity: Contextual learning that goes beyond purely technical knowledge. When we integrate EDI and cultural relativity themes into the experiences, we inherently create integrated learning experiences. --- Tip: Focus on the process and how it impacts individuals to create enhanced integrated learning experiences. --- Example: Have students explore the design of a rice cooker while also exploring different cultural practices in rice production and consumption in different contexts.	Connectivity: Active learning methods are ideal for exploring equity themes as they enable deeper engagement with complex topics through peer interactions. --- Tip: Active learning facilitates integrated learning experiences. --- Example: Students can analyse case studies of human-centred design projects that failed due to cultural blind spots. The activity can be a jigsaw design, where groups discuss different case studies and then swap to share the cultural implications of the project failures with new groups.	Connectivity: Faculty can be trained in equity themes and how these relate to technical and interpersonal skills and sustainable design. This will build their confidence in applying these ideas to inclusive teaching. --- Tip: Shared exploration with students can ease pressure on faculty to be seen as equity champions. It also helps students build confidence and reduces traditional hierarchies. --- Example: A lunchbox learning series can enable faculty to explore universal design principles, consider cultural contexts and product requirements, and integrate sustainability into design decisions, among other equity themes.
Course content that covers multiple perspectives, theoretical standpoints and contributions by people from multiple cultures and backgrounds. (7/8)	Connectivity: A core facet of the integrated learning experience is the representation of diverse stakeholders, perspectives, theoretical standpoints and cultures. --- Tip: Highlight the importance of listening to and enacting the perspectives of people from multiple cultures and backgrounds --- Example: Design an integrated learning experience that asks students to design a renewable energy solution tailored to a rural community. Have the students incorporate the local Indigenous perspectives and state-based energy policies. Integrate environmental and economic perspectives from key stakeholders.	Connectivity: Students can engage more deeply and robustly with the content when actively applying multiple perspectives to the topics they are discussing within their active learning experiences. --- Tip: Active learning should allow individual processing, reflection, and collaborative activities. --- Example: Create a role play for a project where each role is a different stakeholder with a unique perspective and identity. Have students speak from that perspective and collaboratively develop a project plan as a unified group, incorporating each perspective within the plan.	Connectivity: Faculty competence is made more holistic and robust by including diverse perspectives and theoretical standpoints. --- Tip: Multiple perspectives can speak to different cultures, individual identities, and different disciplines within a similar field. --- Example: Faculty can seek to include guest speakers of various disciplinary backgrounds.
Incorporation of the embedding of EDI in the curriculum in classroom observation and peer review activities. (8/8)	Connectivity: A core facet of the integrated learning experience is the representation of diverse stakeholders, perspectives, theoretical standpoints and cultures. --- Tip: Highlight the importance of listening to and enacting people's perspectives from multiple cultures and backgrounds. --- Example: Design an integrated learning experience where students create a renewable energy solution for a rural community, incorporating local Indigenous perspectives, state-based energy policies, and environmental and economic viewpoints from key stakeholders.	Connectivity: When students engage in active and experiential learning through an equity lens, they also learn from the diverse viewpoints and approaches their peers bring to the learning experience. Classroom observations are important to ensure educators get feedback on how culturally safe these are being run. --- Tip/Example: Classroom observers can review the equitable practices present in a peer's product design, considering accessibility and universal design principles.	Connectivity: Incorporating an EDI lens into peer review and observation activities helps engineering faculty identify and address biases in technical content and examples. It also enhances students' understanding of complex engineering concepts across diverse backgrounds.. --- Tip: Younger faculty may be more attuned to equity practices, having been educated under different paradigms than their senior counterparts. --- Example: A peer review program where faculty observe each other's classes and provide feedback on technical content and inclusivity. For instance, a reviewer might notice that all heat engine examples in a thermodynamics class are automotive-based and suggest including examples from other industries, such as power generation in developing countries or cooling systems in varied climates.

APPENDIX: PART 1D (OF 5) CURRICULUM DESIGN
MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (10-12)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 10: Enhancement of Faculty Teaching Competence	Standard 11: Learning Assessment	Standard 12: Program Evaluation
Accessibility of and flexibility in programmes of study that allow students to input on their learning pathways and experiences. (1/8)	Connectivity : Faculty are expected to be teaching and assessing in new ways - these innovations can incorporate methods that allow student input into their learning pathways and experiences. --- Tip: Build Faculty competence in teaching as a 'guide on the side' - facilitator/coach/resource provider - to enable student input into their learning experiences. --- Example: Staff training involves learning how to develop learning activities that are student-driven and open-ended, where the educator is not sure where they will end up (i.e. the task/activity end-point is not fixed).	Connectivity: This standard ensures students are assessed using a variety of methods that are accessible to all and flexible when needed. --- Tip: When redesigning assessments, prioritise accessibility and flexibility while considering potential limitations, such as moderation concerns for students using different task modes. --- Example: Create a project bank with various options for students to choose from and allow them to contribute new ones (with educator feedback on suitability)	Connectivity : It is in the program evaluation that "if in an exit interview, a majority of students reported that they were not able to meet some specific learning outcome, a plan could be initiated to identify root causes and implement changes" These investigations should uncover if a lack of accessibility and flexibility contributed. --- Tip: Make sure students know and perceive that their feedback will be accepted in good faith. --- Example: Share with students what and when changes have been made to the program based on their valuable input.
Accessibility of learning outcomes and/or competence standards. (2/8)	Connectivity : Improving faculty teaching competence is directly related to the accessibility of learning outcomes. --- Tip: Ensure staff know how to use the Advance HE EDI or UDL framework. --- Tip: Faculty familiar with the Advance HE EDI or UDL framework use them to determine whether their learning outcomes or competency standards are accessible.	Connectivity : This standard emphasises the importance of aligning assessments with the learning outcomes. --- Tip: Ensure the learning outcomes that inform learning assessments are accessible. --- Example: The learning outcomes have been carefully considered to ensure they are meaningful for all students; there is flexibility in the learning assessment to support and convey this meaningfulness.	Connectivity: The program evaluation seeks to understand if it is reaching its goals. Presumably, these goals continually change 'with the times'. --- Tip: During evaluation, ask: If the program is changing with the times, are the learning outcomes keeping up? Is everything else keeping up? ---
Considerations of EDI in learning outcomes and/or competence standards. (3/8)	Connectivity: Faculty must develop competencies in inclusive pedagogical approaches to effectively implement EDI-focused learning outcomes, as this ensures all students can engage with and demonstrate mastery of course material through varied, culturally responsive learning experiences. --- Tip: Most institutions have an EDI office that can support Faculty in embedding inclusive practices into teaching and learning. --- Example: Faculty can enhance their own EDI competence by attending workshops on culturally responsive teaching methods and consulting with the university's EDI office. Faculty can redesign their teaching approach to be more inclusive of students' lived experiences.	Connectivity: These two standards are inherently connected through constructive alignment. If EDI is considered within the outcomes, the assessment will be aligned to this and have EDI themes embedded within the form and topic of the assessment. --- Tip: Case studies are effective tools to showcase diverse and inclusive solutions. --- Example: Learning outcome: Design energy systems that are efficient and culturally appropriate for diverse global contexts. Assessment :In a case study, students analyse power plants from various countries, including non-Western examples, considering cultural, economic, and environmental factors in their design.	Connectivity Program evaluations should seek to understand if EDI is considered in learning outcomes and/or competency standards. --- Tip: Draw from professional registration standards to incorporate EDI themes and wording to strengthen accreditation evidence. --- Example: Use the Advance HE EDI framework to evaluate how well EDI is considered throughout the learning outcomes and the course more broadly.
Tackling of the impact of own identity beliefs, cultural assumptions and unconscious biases as part of the design process. (4/8)	Connectivity: Reflexivity assists educators in designing an inclusive curriculum. The benefits of this reflexivity are also felt by educators identifying potential gaps in their teaching knowledge or experience. --- Tip: Cross-disciplinary discussions with educators can leverage diversity in experience when it may be lacking within departments. --- Example: Faculty creates a professional development series called "Inclusive Engineering Education" where faculty members engage in structured self-reflection workshops particularly regarding: 1. Their assumptions about which students are 'naturally good' at engineering. 2. Their implicit expectations about student backgrounds and preparation3. Their communication patterns with students from different cultural backgrounds.	Connectivity: Educators' personal biases and cultural assumptions can significantly impact their assessment methods and their interpretation of student achievement. --- Tip: Use a colour-coded spreadsheet to map out different assessment styles and skill sets used. --- Example: Identify overused assessment types and skill sets used in the curriculum (such as written forms of assessment) and create an assessment regime that is varied and leverages a diverse range of skill sets (such as visual and oral communication)	Connectivity: Integrating educators' identities, beliefs, cultural assumptions, and unconscious biases into curriculum design should result in an evaluation system that values stakeholder feedback and is intentionally inclusive and culturally responsive. --- Tip:Involve diverse stakeholders and use a variety of evaluation methods—student assessment data, industry feedback, internal reviews, and equity consultant assessments. --- Example: Review past curriculum evaluation measures and standards for unconscious bias and cultural assumptions.
Opportunities for students to co-create their curricula. (5/8)	Connectivity: Faculty needs a high level of teaching competence to co-create the curriculum. Student preferences and quality pedagogy may be in conflict through co-creation, so teaching skills and knowledge are critical. --- Tip: Terms like 'student satisfaction' are not always helpful in co-creation because students can be unsatisfied with a program that is pedagogically robust and inclusive. --- Example: Have faculty examine and classify student co-creation suggestions to distinguish between those that are pedagogically sound and inclusive and those that are not.	Connectivity: Students can co-create learning assessments that align with the intended learning outcomes, which will increase their motivation and assist in ensuring adequate coverage. --- Tip: Educator oversight is critical here to ensure accreditation/registration standards are met, so educators must heavily guide assessment co-creation. --- Example: Give students an assessment concept and intended learning outcomes and have students design an assessment task based on these.	Connectivity: Co-creation increases student agency, leading to positive program evaluations. --- Tip: Gain feedback from students specifically targeted towards the co-creation aspects of the program. --- Example: Create a mid-semester survey that asks students to identify benefits and issues related to the co-creation of the curriculum
Course content that facilitates exploration of themes of equality, diversity, inclusivity and cultural relativity. (6/8)	Connectivity: Increased pedagogical content knowledge allows faculty to support students in their learning effectively, and the prioritisation of equity themes in the curriculum facilitates this same goal. --- Tip: Work with students to find similarities between inclusive engineering design and good practice educational design. --- Example: As a faculty, introduce Universal Design for Learning principles across the curriculum.	Connectivity: Themes of equality, diversity, inclusivity, and cultural relativity can be key components and criteria for learning assessment. --- Tip: If equity and cultural relativity themes are embedded in the assessment task, then they should also feature within the assessment criteria and rubric. --- Example: Create a case study assessment that contains inherent cultural bias within product design, have students analyse and identify the bias, and then revise the product brief to address cultural relativity.	Connectivity:A curriculum that covers equity theming integrated into the pedagogical design will achieve a more rigorous quality standard in program evaluations. --- Tip: Ensure stakeholders and those evaluating the program are aware of the commitment to equity theming within the curriculum. --- Example: Create a whole program evaluation survey that asks students whether they felt the program was educationally inclusive, in addition to the inclusive theming in the program content.
Course content that covers multiple perspectives, theoretical standpoints and contributions by people from multiple cultures and backgrounds. (7/8)	Connectivity: Faculty teaching competence can be enhanced through the integration of inclusive educational practices as inclusive practices are closely aligned to quality educational practices, of which diverse representation is a key theme. --- Tip: The best way to enhance and integrate diverse perspectives in faculty teaching competence is by recruiting diverse educators. --- Example: Faculty can analyse which perspectives are prioritised in the curriculum and whether there are any inherent biases present. This is best conducted with multiple faculty and institutional professionals who can contribute perspectives from multiple cultures and backgrounds	Connectivity: A broad range of assessment methods naturally accommodates diverse perspectives. --- Tip: Case studies are a clear way to include diverse perspectives, but beyond introductory courses, students should be encouraged to critically identify different, or missing, perspectives themselves.. --- Example: Include a reflective task where students analyse the perspectives and theoretical standpoints within a task or project, noting whether a broad range was represented or if certain views were prioritised.	Connectivity: When curriculum content, activities, and assessments encourage students to engage with diverse perspectives and cultures, this naturally fosters a sense of inclusion within the student cohort. --- Tip: Consult staff responsible for EDI oversight to evaluate your program and advise on integrating diverse perspectives into the curriculum. --- Example: The program is evaluated by students, industry, faculty, and institutional EDI professionals: groups that reflect diverse cultures and individuals.
Incorporation of the embedding of EDI in the curriculum in classroom observation and peer review activities. (8/8)	Connectivity: By incorporating EDI principles into classroom observations and peer review, faculty can become more aware of diverse student needs and perspectives. This awareness can lead to more inclusive teaching practices that support all students. --- Tip: Use peer review to strengthen faculty competence in designing inclusive educational materials. --- Example: faculty development program where educators peer review curricula with a focus on EDI. Sessions evaluate how well diverse perspectives are integrated into teaching. For instance, case studies featuring only male engineers may unintentionally alienate female students.	Connectivity: Embedding EDI practice into peer review and observation of assessment helps educators gain a deeper understanding of diverse perspectives and learning approaches while also developing their ability to assess and provide feedback on learning outcomes. --- Tip/Example: Select reviewers for assessments who combine discipline knowledge and EDI familiarity and perform these reviews in a blinded fashion	Connectivity: The connection lies in their shared goal of continuous improvement and comprehensive assessment of educational programs. --- Tip: Action plans and review cycles are an effective wait to maintain positive change over time. --- Example: A systematic evaluation tool that focuses on inclusive teaching practices and equitable student engagement across the program. A diverse group of peers evaluates the quality of this implementation.

APPENDIX: PART 2A (OF 5) CURRICULUM DELIVERY
MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (1-3)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 1: Context	Standard 2: Learning Objectives	Standard 3: Integrated Curriculum
Creation of accessible, safe and collaborative environments of mutual respect and honesty conducive to student learning. (1/8)	Connectivity: The context allows for project-based learning experiences where students collaboratively design, build, and operate sustainable solutions addressing real-world challenges, ensuring accessibility and inclusivity in team dynamics. --- Tip/Example: Faculty can further support this by fostering a culture of respect, safety, and honesty through clear guidelines, constructive feedback, and promoting interdisciplinary teamwork reflective of professional engineering environments.	Connectivity: By aligning with program learning outcomes that emphasise interpersonal skills like collaboration, communication, and respect, the framework fosters a culture where students develop the ability to work together in a safe, inclusive, and supportive environment, cultivating mutual respect and honesty that are essential for their academic and professional growth. --- Tip/Example: Seek inspiration for learning outcomes related to inclusion through the institutional graduate outcomes and student charter.	Connectivity: Designing courses that connect related content and skills fosters a cohesive learning journey. Students are encouraged to collaborate, value diverse perspectives, and apply their knowledge in real-world contexts, creating an environment where respect, honesty, and teamwork are essential. --- Tip/Example: Respect and honesty grow in spaces of psychological safety. Educators can model respectful communication and encourage students to value diverse perspectives during discussions and problem-solving
A range of teaching approaches and learning activities that are accessible and encourage active participation of all students. (2/8)	Connectivity: This incorporates diverse, hands-on learning experiences such as case studies, simulations, and team-based projects where students actively engage in the entire lifecycle of a sustainable engineering solution. --- Tip: Active participation in real-world sustainability projects increases student motivation. --- Example: CDIO, as the context for engineering education, innately embraces learning activities that encourage active participation, and care will need to be taken to ensure accessibility and equitable participation.	Connectivity: Program learning outcomes guide the design of a range of accessible teaching approaches and learning activities that actively engage all students, fostering participation and reinforcing both individual and collaborative skill development in line with program goals and stakeholder needs. --- Tip/Example: Benchmark program learning outcomes against industry competency standards, paying particular attention to teamwork and communication expectations across the industry.	Connectivity: Students experience a cohesive learning journey that emphasises the practical integration of both sets of competencies (personal, interpersonal, and professional skills with technical knowledge), ensuring active participation and, through accessible and inclusive learning activities, deep engagement with all aspects of their education. --- Tip/Example: Implement activities where students collaboratively solve problems under changing conditions such as errors, client pushback, and system breakdown or failure. This approach combines theoretical learning with practical application.
Knowledge of student cohorts and adaptation of curriculum delivery to cohort and individual requirements. (3/8)	Connectivity: By continuously adapting curriculum delivery to address the backgrounds and individual needs of students, instructors ensure that each cohort develops the necessary skills to conceive, design, implement, and operate sustainable engineering solutions effectively. --- Tip: World events can reshape education, highlighting the need to reassess skill levels for each new cohort. --- Example: Develop a skills diagnostic assessment for each new cohort to establish a baseline of their ability to conceive, design, implement, and operate.	Connectivity: Support the adaptation of the curriculum to the unique needs of student cohorts, ensuring that curriculum delivery is tailored to both group and individual requirements, thus enabling students to achieve these targeted learning outcomes effectively. --- Tip: Addressing cohort-specific challenges helps level the playing field, starting with learning outcomes. --- Example: Use diagnostic activity data from Standard 1: Context to assess whether learning outcomes are appropriate for each cohort.	Connectivity: The curriculum is a cohesive structure where each course builds on the others, linking technical knowledge with practical skills like collaboration, communication, and problem-solving, while considering the unique needs of each student cohort. --- Tip: Addressing cohort-specific challenges helps level the playing field and mitigate potential disadvantages. --- Example: If the cohort has a larger than usual number of students for whom English is a second language, you could implement additional communication scaffolding and visual aids and reduce the grammatical complexity of the written information while maintaining disciplinary terminology.
Empowerment of students to take responsibility for their own learning and that of their peers, acting as partners in their learning experience. (4/8)	Connectivity: In a CDIO-based program, students work on real-world projects where they collaborate as partners in every stage of the lifecycle, from conceiving ideas to operating solutions, taking ownership of both their individual and collective learning. This hands-on approach not only develops technical skills but also fosters accountability, as students actively contribute to decision-making, peer feedback, and continuous improvement throughout the engineering process. --- Tip: Empower students to take responsibility for their own learning and that of their peers within the CDIO framework. --- Example: Through the CDIO process, students engage in peer learning and take responsibility for their learning. This can be scaffolded and prioritised through the co-creation of systematic, curriculum-wide expectations.	Connectivity: Establish specific and detailed learning outcomes for both technical and non-technical skills, ensuring collaboration, co-design and peer learning as a critical professional skill development is reflected. --- Tip: Co-design allows students to take responsibility for their learning and increase autonomy and agency. --- Example: Co-design learning outcomes that are aligned to subject learning outcomes so that students can create their own unique learning pathway that is fundamentally also constructively aligned.	Connectivity: Students engage in activities that blend technical learning with personal and interpersonal skill development, such as collaborative projects, teamwork, and leadership roles. These experiences require them to take initiative, solve problems together, and reflect on their own learning, thus fostering a sense of responsibility for both their personal growth and the success of their peers. --- Tip: Consider the digital tools that can be systematically integrated across the curriculum that enhance peer learning. --- Example: Create a mapping document related to peer-based learning skills and how they are integrated across the curriculum.
Opportunities for students to relate course content to their own experiences, encouraging the sharing of diverse perspectives and interpretations. (5/8)	Connectivity: Students work on real-world projects where they apply engineering principles to solve local or global challenges, such as designing sustainable technologies or systems. This approach encourages students to draw on their personal experiences, engage with peers from diverse backgrounds, and collaborate in multidisciplinary teams, fostering an environment where different perspectives shape innovative solutions. --- Tip: Showcase the integration of diverse perspectives within CDIO to industry and the CDIO community. --- Example: Student experiences are prioritised with the content within the implementation of CDIO.	Connectivity: Program learning outcomes can be designed to incorporate interactive, inclusive, real-world engineering challenges. --- Tip: Align program learning outcomes with the institution's graduate attributes for a real commitment to professional skill development. --- Example: Mapping of program learning outcomes can be unpacked into modular, weekly, or topic-based learning outcomes that align with active collaboration in mixed groups that guide students in applying product, process, system, and service-building **skills**.	Connectivity: By mapping skills development to courses and activities, students are encouraged to relate what they learn to personal experiences, fostering diverse perspectives and deeper connections to the material. This creates a holistic learning environment where academic content and practical skills are mutually reinforcing. --- Tip: Implementing reflective practices can help students connect course content to their personal experiences and cultural backgrounds --- Example: Map the professional skill development of the student across the course and integrate the development of these skills into a programmatic ePortfolio.
Opportunities for students to work interactively in diverse and mixed groups. (6/8)	Connectivity: CDIO, as the context for engineering education, requires students to collaborate in teams. By focusing on the diversity within these groups, alignment is easily achieved. --- Tip: Diversity can encompass cultural, disciplinary, gender, and various societal, environmental, and disciplinary perspectives. Ensure multiple aspects are considered. --- Example: Structure multidisciplinary projects where students from different engineering disciplines collaborate throughout the product or system lifecycle, from conception to operation. This mirrors real-world engineering environments, offering opportunities for students to work in diverse teams, integrating their expertise to develop sustainable, interdisciplinary solutions.	Connectivity: While diversity in group formation is not inherently a component of learning outcomes, the program learning outcomes can integrate sharing diverse perspectives through collaboration and team skill learning outcomes. --- Tip: Seek clarity from graduate learning outcomes on how collaboration in diverse groups is defined in the institution. --- Example: Design learning outcomes that not only meet technical and personal skills learning outcomes but also develop critical interpersonal competencies, such as teamwork, communication, and leadership, as part of a holistic educational experience.	Connectivity: By intentionally incorporating programmatic, collaborative activities in diverse, mixed groups, the curriculum develops fundamental teamwork and communication skills, allowing students to practice and refine both their technical expertise and their ability to engage effectively with others in a professional setting. --- Tip: Students will not inherently know how to engage effectively with each other: this is a learned skill that will need scaffolding and support. --- Example: Develop a bank of case studies from industry that explore how businesses have leveraged diversity in collaboration in positive and transformative ways.
Integration of themes of equality, diversity and inclusivity into learning materials and activities. (7/8)	Connectivity: Adopting CDIO in engineering education inherently prioritises EDI themes by integrating environmental, social, and economic sustainability throughout the lifecycle. --- Tip: As a faculty, unpack what environment, social and economic sustainability looks like in the context of the course in relation to EDI themes. --- Example: Through the CDIO process, students could work on projects that address real-world challenges, such as designing sustainable solutions for underserved communities, and ensuring diverse voices are included in problem-solving and decision-making processes.	Connectivity: The contextual elements of program learning outcomes are an ideal place to incorporate EDI themes. --- Tip: Learning outcomes usually have a verb, content and may include context. For example: Design (verb) engineering solutions (content) that accommodate a spectrum of physical abilities and cognitive differences (context). --- Example: Ensure that learning outcomes are representative of a diverse population and varied in their skill focus.	Connectivity: By purposefully mapping learning outcomes and activities, educators can embed equality, diversity, and inclusivity within the curriculum, ensuring these values are reflected in both program content and student interactions in projects. --- Tip: This strategy creates a more inclusive learning environment, integrating these themes throughout the entire educational experience rather than treating them as retroactive add-ons. --- Example: Develop an integrated curriculum that helps students design appropriate technology solutions with respect for local cultural practices that also address technical needs.
Accessible learning materials and resources available to students in advance of curriculum delivery. (8/8)	Connectivity: In CDIO implementation, support from program leaders is crucial to maintaining reform initiatives, particularly in scheduling and workload to provide accessible resources before the curriculum begins. --- Tip: Leaders can prioritise this by stating that all curriculum resources will be finalised in advance of the semester, and faculty will provide adequate workload compensation for this to occur. --- Example: When engaging faculty in CDIO implementation, ensure the project timeline allows ample time for preparation.	Connectivity: Aligning accessible resources with clearly defined learning outcomes ensures that students can actively engage with personal, interpersonal, and technical skills in a structured manner, fostering better preparation and application during their studies. --- Tip: Resources offered in advance can still be aligned to learning outcomes but be reflective of a lower expected skill or knowledge level to better scaffold students. --- Example: Suggest a Khan Academy or Ted Ed lesson as a resource aligned with learning outcomes that can be made available prior to the introduction of more advanced resources.	Connectivity: Allowing students to access materials in advance helps them visualize how each course contributes to the broader learning framework, fostering a stronger understanding of how the program supports their professional development. --- Tip: Colour code primary concepts and disciplines to visually represent the breadth of integration across the curriculum. --- Example: In a course map, list critical resources and information that connect the curriculum. For instance, if a textbook is partially used in one subject, are alternative chapters used in another? This can also help faculty identify content overlap and avoid double teaching.

APPENDIX: PART 2B (OF 5) CURRICULUM DELIVERY MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (4-6)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 4: Introduction to Engineering	Standard 5: Design-Implement Experiences	Standard 6: Engineering Learning Workspaces
Creation of accessible, safe and collaborative environments of mutual respect and honesty conducive to student learning. (1/8)	Connectivity: Accessible learning materials and resources should be provided in advance to support student success, ensuring they are prepared to engage with and build upon essential skills throughout the program. --- Tip/Example: Co-create communication expectations with students focused on respect, openness, and inclusion during the introduction to the engineering program, maintaining these throughout the course. Educators can invite all students to share their expectations and needs to ensure a comfortable and safe learning	Connectivity: Early design-implement experiences are simple and achievable, helping students build confidence and teamwork. Later, more advanced projects challenge students to apply their knowledge and work together on complex problems. This progression helps students develop technical skills and improve communication and collaboration, all in an environment of mutual respect and honesty, reflecting the cooperative culture of engineering. --- Tip/Example: Open discussions and Q&A sessions throughout the design-implement experience encourage students to share ideas without fear of judgment, promoting honesty and mutual respect.	Connectivity: For student success in hands-on and active learning activities, the environment must be safe and accessible, allowing students to share their needs and be vulnerable with educators and peers. --- Tip: When introducing a new workspace, artefact, or teaching modality, invite students to share any challenges or barriers they may face. --- Example: Choose physical or virtual learning environments that are neutral and unfamiliar to all disciplines involved, helping to eliminate unconscious biases and encourage collaboration.
A range of teaching approaches and learning activities that are accessible and encourage active participation of all students. (2/8)	Connectivity: Engineering practice can be made tangible from the start, using engaging, hands-on activities that draw students into real-world problem-solving. It actively involves students through team exercises and encourages the development of both technical and interpersonal skills, ensuring all students participate in and connect with the field of engineering from day one. --- Tip/Example: Offer varied task formats such as oral presentations, written reports, or visual demonstrations. This allows students to showcase their strengths and encourages broader participation.	Connectivity: Engage students in design-implement experiences, progressively building their skills through both basic and advanced projects. These experiences, designed to encourage active participation, offer students opportunities to apply their learning in real-world contexts, fostering deeper understanding, critical thinking, and the ability to address societal needs through accessible and inclusive activities. --- Tip/Example: Roles within the team (Manager, facilitator, designer, tester) are rotated to ensure all students experience different aspects of the project, fostering equity and skill development.	Connectivity: Activities must be accessible to ensure more students can engage. Practical, real-world aligned activities are motivating and encourage active participation. --- Tip/Example: Offer a variety of contexts for activities and address concerns or needs raised by students. For example, when collaboratively analyzing a physical structure, provide options for different modes or formats of analysis (e.g., using a digital tool, whiteboard, or physical model).
Knowledge of student cohorts and adaptation of curriculum delivery to cohort and individual requirements. (3/8)	Connectivity: The introductory engineering course is designed to be engaging and adaptable to the unique needs of diverse student cohorts. By including problem-solving exercises, teamwork, and personal development, it tailors the curriculum to foster early engagement and motivation while addressing the varying learning requirements, setting them up for success in more advanced courses. --- Tip: Adapting curriculum delivery to support one group's specific needs can have a positive flow on effects to all students. --- ExampleIf a cohort has the necessary math prerequisites but limited application skills, redesign the course to progressively introduce mathematical concepts alongside disciplinary ones.	Connectivity: Adapting the complexity of these experiences based on student needs, the curriculum ensures that students progress through increasingly challenging design tasks, reinforcing their learning and aligning with their career aspirations and professional growth. --- Tip: When a student can see a true connection to their future career, they will often be more engaged in the learning. --- Example: Individual requirements could also look at individual student interests and passions within the engineering to tailor new projects in the interest area of the cohort.	Connectivity: Students will enter their subjects with a diversity of knowledge bases and learning needs and this plays out in their hands-on learning. They will need to have a strong foundation to engage in practical tasks and some may need greater depth in some areas or may already be familiar with others --- Tip: Use formative tasks and self-assessment to assess student knowledge and needs, then adjust practical tasks to maximize productivity. --- Example: Students need to produce a 'missing piece' for a miniature structure that will make it stable. They will be 3D printing for the first time in this so the educator asks their familiarity with 3D printing and groups them so that each group has more and less experienced members so they can help each other.
Empowerment of students to take responsibility for their own learning and that of their peers, acting as partners in their learning experience. (4/8)	Connectivity: The course immerses students in real-world engineering tasks early on, where they practice problem-solving and design in teams. By engaging in these activities, students take responsibility for their own learning while supporting each other, fostering a collaborative environment and preparing for future engineering challenges. --- Tip: Discuss with students what taking responsibility for learning means in a Higher Education context and clarify faculty expectations.. --- Example: In the introductory course, acquaint students with co-created group contracts that establish ways of working to improve communication and accountability in project-based learning.	Connectivity: Empower students through scaffolding design-implement experiences that progressively increase in complexity, allowing them to take responsibility for their learning. As they engage in real-world projects, students develop their skills at each level, while collaborating with peers to solve problems, reinforcing both individual and collective responsibility. --- Tip: Use basic and advanced design-implement experiences to develop students' peer feedback, collaboration, and autonomy within a shared workload. --- Example: Use formative peer feedback to scaffold students' skills in the basic design-implement experience, then extend this with summative peer review in the advanced experience.	Connectivity: Students will be most engaged and motivated towards practical, hands-on learning when they feel they have agency over what, how and why they participate in these tasks. --- Tip: Encourage use of self and peer assessment to help students determine their own learning needs and readiness --- Example: Students work on a large group project over the semester and have open access to learning workspaces with a variety of different tools within. They make decisions of when and how to use those spaces to meet their project goals in consideration of a shared need for access by other teams.
Opportunities for students to relate course content to their own experiences, encouraging the sharing of diverse perspectives and interpretations. (5/8)	Connectivity: Immediately applying engineering principles to real-life problems encourages students to relate course content to their own experiences and perspectives, fostering a diverse range of interpretations and enhancing motivation for the field of engineering. --- Tip: Teaching empathetic and user-centred design principles can help students relate course content to diverse human experiences --- Example: In the introductory course, collaborate with non-profit organisations to expose students to real-world challenges faced by diverse populations. Provide an online space for students to reflect on these experiences collaboratively throughout the course.	design-implement experiences, students apply course concepts to tangible projects, linking theoretical knowledge to real-world situations. This process helps them integrate their own experiences and viewpoints, enhancing their understanding of both technical and societal aspects of engineering.engineering. --- Tip: Sharing personal experiences in group work can be confronting, so it's important to collaboratively define respectful communication expectations beforehand. --- Example: In design-implement experiences, encourage students to share their approaches to solving problems and facilitate discussions that explore the cultural or experiential influences on their strategies.	Connectivity: The physical and virtual learning environments can be leveraged to create safe and inclusive spaces for students to be able to connect the course content to their own experiences and also share their perspectives with others. --- Tip: Most online tools may be anonymous to other students, but identities can be accessed by educators in case of any breaches in student conduct. --- Example: Culturally unsafe topics, such as whistleblowing, can be perceived differently by students with different cultural backgrounds. Creating an anonymous space within the digital environment allows honest opinions to be voiced without fear of reprisal.
Opportunities for students to work interactively in diverse and mixed groups. (6/8)	Connectivity: Immerse students in real-world engineering practice from the start with hands-on exercises that require collaboration in diverse teams. --- Tip: By working interactively in mixed groups, students develop not only technical skills but also key interpersonal abilities like communication, teamwork, and problem-solving, which are vital for their future engineering roles. --- Example: In the introductory course, create opportunities for cross-disciplinary project work to showcase the importance of collaborative practice. This also allows faculty to incorporate diversity in perspective into disciplines that may be dominated by specific cultures or genders.	Connectivity: Design-implement projects require collaboration, promoting teamwork among students from diverse backgrounds, which mirrors real-world engineering practice. --- Tip: The success of a project depends on effective interaction and cooperation across disciplines and perspectives. --- Example: Assign specific project roles for students and integrate a comparative peer reflection where they can express the challenges of their role in the project and how they managed them and compare their experience to a peer with a different project role.	Connectivity: Technology in the digital learning workspace can create diverse working groups for interactive activities and collaboration. The physical learning space can be used similarly, with active learning room layouts and intentionally diverse groups based on positionality, experiences, and disciplines. --- Tip: Change groups regularly to encourage full participation and reduce the risk of placing dominant students with softer-spoken ones. Guidelines for equal participation can also help. --- Example: Most Learning Management Systems can randomly generate and re-distribute groups for subsequent activities, which is safer than assuming students' culture or gender based on their names.
Integration of themes of equality, diversity and inclusivity into learning materials and activities. (7/8)	Connectivity: Learning materials and activities in the introductory engineering course are designed to expose students to a range of engineering contexts that reflect diverse global challenges and innovations. --- Tip: Include exercises to help students recognise and address bias, fostering inclusivity and equity in their future engineering practice. --- Example: Use case studies and examples from underrepresented groups in engineering to help students appreciate the contributions of diverse engineers.	Connectivity: Provide opportunities for students to engage in real-world contexts that address diverse societal needs and promote inclusive practices in product, process, system, and service development. --- Tip: Showcasing poor practice within industry can inspire students to become future equity champions in engineering design. --- Example: Collaborate with industry to create case scenarios that expose students to real-world challenges faced by diverse populations. Have students consider alternatives to the existing product, plan, or service that caters more explicitly to a diverse population.	Connectivity: The physical and digital learning infrastructure can be a practical space for identifying different needs and integrating themes of equality, diversity and inclusivity into learning materials and activities. --- Tip: Leverage institutional teaching and learning support services for ideas on integrating EDI themes in both digital and physical spaces. --- Example: Offer a component of activities to explore the outcome of a design if one important fact of the client changed. For example, how would the product design shift if the client were a parent of young children or a carer of a disabled adult child?
Accessible learning materials and resources available to students in advance of curriculum delivery. (8/8)	Connectivity:To ensure students are prepared, accessible learning materials and resources are made available in advance, facilitating engagement with the core concepts and enabling a smooth transition to more advanced coursework. --- Tip: The introductory course can use existing curriculum resources or materials that offer the same information but at a less advanced reading level or level of disciplinary difficulty. --- Example: Introductory courses can offer a pre-subject diagnostic quiz that determines the students' prior knowledge and offers supplementary resources if the student chooses to review or if there is a genuine gap in prior knowledge.	Connectivity: By providing accessible learning materials ahead of time, students can better prepare for design-implement experiences, ensuring they have the foundational knowledge needed to successfully tackle both basic and advanced design challenges. --- Tip: Providing accessible resources in advance of curriculum delivery can be for building foundational knowledge or providing contextual information and background. --- Example: Provide background information for a project prior to the class to leverage the class time to action the design-implement experience.	Connectivity: Anxiety and other stress-based disorders are amplified by the unknown. Something as simple as offering a building layout or classroom map in advance of the class can help alleviate stress in students. --- Tip: Have you ever been to a job interview and stressed about finding the location and the room? This is not dissimilar to how many students feel when trying to find their workspace for the first time. --- Example: Many institutions now have digital wayfinders that offer directions to locations and showcase the full layout of the classrooms. Ensure students are aware of these well before curriculum delivery.

APPENDIX: PART 2C (OF 5) CURRICULUM DELIVERY
MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (7-9)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 7: Integrated Learning Experiences	Standard 8: Active Learning	Standard 9: Enhancement of Faculty Competence
Creation of accessible, safe and collaborative environments of mutual respect and honesty conducive to student learning. (1/8)	Connectivity: Learning experiences which integrate different stakeholder perspectives, social issues, themes, etc. will already provide a variety of activities that motivate students to engage. Making those activities accessible will remove additional barriers limiting student ability to integrate and apply their learning --- Tip: To ensure a broad integration, motivation and accessibility, ensure a diversity of voices contribute to the design	Connectivity: As per row 1, standard 6 --- Tip/Example: Sessions can be inclusive by allowing students to work through activities at their own pace providing feedback through self-assessment, peer-assessment, and educator-assessment.	Connectivity: Faculty need to engage in effective collaboration themselves to produce effective engineering artefacts and solutions, and being skilled in this allows them to role-model the practice for students. --- Tip/Example: Consider providing recordings of collaborative conversations between stakeholders in a project that demonstrate accessible, safe and respectful collaboration, which students can learn from.
A range of teaching approaches and learning activities that are accessible and encourage active participation of all students. (2/8)	Connectivity: Learning experiences that integrate different stakeholder perspectives, social issues, themes, etc., will provide a variety of activities that motivate students to engage through interest or relatability. Making these activities accessible will remove additional barriers limiting student ability to integrate and apply their learning. --- Tip/Example: To ensure a broad integration and accessibility, a diversity of voices contribute to the design.	Connectivity: As per row 2, standard 6 --- Tip/Example: Students can research historical perspectives through multiple sources and formats and prepare arguments in flexible formats (written, visual, oral). A structured debate requires critical analysis and application of historical concepts, making complex historical thinking accessible through active engagement.	Connectivity: Faculty competence is not just about subject expertise—it includes the ability to create accessible learning experiences and facilitate active participation through varied pedagogical strategies. --- Tip/Example: Create a community of practice for inclusive teaching practices and how they can be explored in the various disciplines. Showcase the learning through regular faculty presentations.
Knowledge of student cohorts and adaptation of curriculum delivery to cohort and individual requirements. (3/8)	Connectivity: Providing an integrated experience means connecting together a wide variety of knowledges and skills into a cohesive whole. Each cohort and student may differ considerably in their skill and knowledge level. --- Tip: Form groups based around a diversity of abilities to maximise how students learn from one another (their near-peers for Vygotskian social constructivism) --- Example: The educator asks students to self-rate their abilities in the relevant knowledges required for the coming assessment and forms groups where the strengths of one student supports the challenges of another.	Connectivity: Active learning techniques, particularly group-based ones, help students consolidate and expand their skills and knowledge beyond an initial level, stretching them based on their readiness. Group activities also leverage the diverse knowledge within the group for the benefit of all members.. --- Tip: Plan extension opportunities for students or groups who need further challenge, and provide additional scaffolding for those who require more support. --- Example: In class, students who finished early had the option to either tackle a challenge task or guide another group (without doing the task for them) to solve it successfully.	Connectivity: Faculty need to have a strong understanding of the subject matter in order to present it in different ways suitable for different learning cohorts. This is similar to how staff may calibrate their communication of technical concepts for a layperson audience but has multiple levels. --- Tip: Faculty with recent industry experience can better tailor content to different student cohorts' needs. --- Example: Analyse student prior knowledge, cultural backgrounds, learning preferences, and professional aspirations. Map these against staff responses to the same ideas, and use this to inform professional development and identify champions.
Empowerment of students to take responsibility for their own learning and that of their peers, acting as partners in their learning experience. (4/8)	Connectivity: Integrated learning experiences naturally bring in a greater level of motivation and interest for the concepts being learnt. In these cases, students are far more likely to do independent investigation, and where the learning culture encourages this, support one another's learning. --- Tip: Consider choice in assessment and learning experiences in relation to student empowerment and autonomy. --- Example: Situate the experience with a variety of real-world case studies and scenarios that will engage student interest, leave enough complexity that answers are not obvious so students need to stretch themselves.	Connectivity: Active learning practices that leverage social learning naturally involve peer-to-peer support. When students take responsibility for their learning, they are more prepared and able to benefit from active learning activities. --- Tip: Get students to share brief reflections and identify actions for themselves at the close of an activity to maximise the learning-focus therein. --- Example: Students work in groups of 4 to develop a laboratory safety plan for an upcoming experiment. As part of this, they need to do some independent learning to determine suitable storage materials and temperatures	Connectivity: A strong knowledge of the subject matter and skills involved are essential if faculty are to help students be more independent and collaborative in their learning. This is related to the level of technical knowledge required to provide meaningful scaffolding to students. --- Tip: Consider what will provide productive levels of challenge and complexity for students, and think about questions that will spark their curiosity. --- Example: Faculty can partner with local companies to identify common design challenges faced by industry professionals. As part of the CDIO process, students can collaborate with these companies to explore similarities and differences in design challenges
Opportunities for students to relate course content to their own experiences, encouraging the sharing of diverse perspectives and interpretations. (5/8)	Connectivity: These standards are connected through integrated learning experiences that incorporate lived experiences and consider diverse perspectives. --- Tip: Especially in the early years, students may not have a lot of technical experience to offer their experiences. Case studies can be helpful to bridge this gap. --- Example: Have students analyse a product's design from a social perspective. Use a series of questions that allows students to examine the end user, their community, their culture, and how that user's perspective may differ from the students' own views and experiences.	Connectivity: These standards are interconnected as active learning experiences often incorporate lived experiences and diverse ways of being, prompting consideration of multiple perspectives. --- Tip: Sharing diverse perspectives does not have to exclusively focus on the student cohort, it can mean exploring the perspectives of the community that the cohort is connected to. --- Example: Have students design a transport and parking solution for a large institution, considering staff and students who travel from various distances and have different abilities and needs.	Connectivity: Creating space for faculty to be open and honest with their own disciplinary skill gaps allows staff to speak from their own perspectives, and work together in a form of mutual trust and transparency to develop professionally. --- Tip: Publicly identifying skills gaps is a risky space and will require openness, transparency, and leading by example from senior leaders. --- Example: Create an internal reflective support platform that allows faculty to openly reflect on their experiences and skill gaps whilst also connecting them with support.
Opportunities for students to work interactively in diverse and mixed groups. (6/8)	Connectivity: Injecting disciplinary diversity into integrated learning experiences can help students to see the broader implications of their work and how it intersects in other fields of engineering. --- Tip: Design integrated learning experiences that deliberately incorporate teamwork, collaboration and reflection to ensure more productive, diverse learning experiences. --- Example: Incorporate case studies that explore the impact of engineering solutions on different social groups and emphasise the value of inclusivity, the program can foster an environment where all students contribute to creating solutions	Connectivity: Collaborative, multidisciplinary active learning experiences, at their core, are interactive. Care and consideration for ensuring a broad range of perspectives are offered and included is essential for creating diverse teams that address complex, real-world problems. --- Tip: Have an awareness of cultural tensions and current events when forming groups and have a co-designed plan for managing conflict if it arises. --- Example: If diverse perspectives are not obvious or inherent in the student base, case studies or role plays can be useful in familiarising students with diverse perspectives when there is a lack of diversity in the cohort.	Connectivity: Faculty must be able to work in diverse and mixed groups to serve as role models as contemporary engineers. --- Tip: Lead by example and demonstrate comfort and flexibility with a difference. --- Example: Hold interdisciplinary learning days for faculty to showcase new trends and research in their fields and require presenters to design discussions around connecting the research to different disciplines within engineering.
Integration of themes of equality, diversity and inclusivity into learning materials and activities. (7/8)	Connectivity: These can be connected by viewing learning as a multidimensional process that recognises that true skill development is inherently intertwined in social context and human diversity. --- Tip: Students will be able to better identify the meaningful change they can bring to the field by integrating technical skills with social awareness. --- Example: Design an activity that analyses the progression of inclusive engineering designs alongside the human rights advocate and catalysts for change.	Connectivity: Students can critically examine themes of equality, diversity and inclusivity within any active learning task, so long as they are directed to do so through the task instructions. --- Tip: Consider socially anxious and/or introverted students when conducting active learning. Active learning is not about constantly speaking but about constantly applying. --- Example: Create a think-pair-share activity that prioritises the 'think' aspect, encouraging students to openly reflect on their own critical biases in the formation of their opinion before launching into the 'share' stage of the activity.	Connectivity: Through these principles, faculty are encouraged to broaden their understanding and teaching of the engineering discipline and how it intersects with diverse perspectives and inclusive practices. --- Tip: Leverage AI technologies in a way that questions faculty's existing practice. --- Example: Develop an internal chatbot that questions faculty on historical disciplinary practice, asking faculty to articulate their continued validity or to challenge the inclusivity or positionality of existing practice.
Accessible learning materials and resources available to students in advance of curriculum delivery. (8/8)	Connectivity: Advanced access to resources in integrated learning experiences enhances students' self-directed learning, prioritisation, and time management—key skills for engineering disciplines. --- Tip: Instead of requiring students to review resources before the integrated learning experience (e.g. flipped classroom), emphasise preparation and reward well-prepared students with feedback on the depth and consideration of their responses. --- Example: Create a project-based activity focused on one business case study. Provide pre-learning resources on the company profile, historical gains, and losses. While not essential for the project, these resources will add depth to the discussion, and students who engage with them will produce higher-quality outcomes.	Connectivity: Advanced access to resources in an active learning context means that students are able to mentally and cognitively prepare for activities and learning concepts in advance, increasing autonomy and alleviating the anxiety that presents itself in unknown situations that require social interaction and engagement. --- Tip: Educators do not need to offer all resources prior to engagement, they can give students an idea of the topics that will be covered and the types of activities that will be present in the active learning experience. --- Example: If the active learning experience involves a role-play, release the role-play cards prior to the class so that students with anxiety can come to class with an understanding of what types of interactions they will be expected to participate in.	Connectivity:Faculty need to have sufficiently strong disciplinary knowledge and professional skills to be able to produce accessible learning materials in a variety of ways. --- Tip: Interdisciplinary sharing circles can be a collaborative way of sharing new disciplinary research and ideas. --- Example: An interdisciplinary sharing circle produces artefacts that can be shared among Faculty that enhances the accessibility of learning materials.

APPENDIX: PART 2D (OF 5) CURRICULUM DELIVERY
MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (10-12)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 10: Enhancement of Faculty Teaching Competence	Standard 11: Learning Assessment	Standard 12: Program Evaluation
Creation of accessible, safe and collaborative environments of mutual respect and honesty conducive to student learning. (1/8)	Connectivity: The ability to create safe, collaborative learning environments is essential for students to work in groups and learn from each other. --- Tip/Example: Provide opportunities to highlight faculty who are effective in these practices and space for educators to observe and learn from each other's teaching practice. Create opportunities for faculty to shadow colleagues who excel at participatory teaching methods	Connectivity: Assessment must reflect true student ability, so students should be able to safely share any barriers they face to avoid being disadvantaged compared to their peers. --- Tip: When introducing a new assessment task, invite students to share any challenges or barriers that may arise for the student cohort. --- Example: Towards the start of the teaching period, students are invited to anonymously share their needs and barriers around assessment. With the release of each assessment and later individual results, students are invited to share how those barriers relate to the tasks and how any mitigation approaches are helping.	Connectivity: In order to genuinely engage in using student voice to evaluate a program, those students need to feel safe to share their experiences without consequence. --- Tip/Example: Provide opportunities to be anonymous and/or to share with staff who have or will not be involved in their future assessment.
A range of teaching approaches and learning activities that are accessible and encourage active participation of all students. (2/8)	Connectivity: An understanding of how to provide a variety of teaching approaches and mechanisms to ensure active participation is key to effective teaching in general --- Tip/Example: Provide tipsheets, guidelines and examples for teaching staff about the design of learning activities with opportunities for peer review of colleagues.	Connectivity: For assessment to accurately measure student ability, students must engage in learning activities that offer varied learning methods and multiple assessment points. Task equivalence requires oversight and moderation. --- Tip: Regularly measure student progress informally and use this information to determine further learning needs required to support their success in formal assessment. --- Example: Educators use a simple rubric to rate student performance against key session outcomes. After class, the subject coordinator reviews common mistakes to suggest further learning nee	Connectivity: Inclusive teaching approaches can provide important data for program evaluation systems. Defining what active participation looks like and how to collect this data accurately and appropriately is integral to the evaluation. --- Tip/Example: Where possible and known, respectfully collect and analyse participation rates across demographic groups for different learning activities.
Knowledge of student cohorts and adaptation of curriculum delivery to cohort and individual requirements. (3/8)	Connectivity: Calibrating curriculum delivery to the appropriate level for students is essential for maximizing learning. This connection focuses on understanding student needs and ensuring faculty can effectively meet them. --- Tip: Create a continuous improvement loop where knowledge of students informs teaching approach, and teaching competence enables better adaptation to student needs. --- Example: Use a variety of low-stakes formative tasks to assess student learning needs and showcase past faculty adaptations, creating a bank of successful adjustments.	Connectivity: There is a minimum useful standard of knowledge required for students to meet subject requirements and there are levels of performance beyond this. Assessing students effectively against these means identifying over multiple episodes of assessment where each student is tracking. --- Tip: While all students can complete the same core project, assessment options could include specialised components tailored to students' backgrounds and career goals.. --- Example: Use developmental rubrics to distinguish between the minimum acceptable knowledge and more advanced levels, ensuring assessments capture student success and offer improvement recommendations.	Connectivity: Evaluating the program necessarily means whether it was able to successfully get students to the required levels in the knowledge base. More effective evaluations will consider the starting point for each student and how (in aggregate) their learning needs were catered for to allow them to succeed (and if not how the program should change) --- Tip: Track student knowledge development in aggregate over and within subjects to determine necessary learning interventions
Empowerment of students to take responsibility for their own learning and that of their peers, acting as partners in their learning experience. (4/8)	Connectivity: Students who are more self-directed and engaged in peer learning tend to be more successful, a key principle in many teaching philosophies. However, fostering this requires explicit training and guidance to establish the right culture and provide necessary scaffolding. --- Tip: Create tip sheets for faculty on reflective prompts that encourage student collaboration --- Example: Offer professional development to help faculty develop skills in relinquishing control over power, choice, content, and instruction. Support them in guiding students and encourage exploring the discomfort of facilitating projects without complete expertise in the discipline.	Connectivity:Any assessment which is providing a meaningful evaluation of student achievement will not simply ask them to reproduce the exact work that has been solved for them. It will need to stretch them and thus with the right learning culture should push them towards self-direction. In cases of team assessment the peer support aspect applies as well. --- Tip: Tie assessment tasks to motivating contexts for students and include enough complexity that students will need to weigh up different options to meet the assessment outcomes. --- Example: Integrate peer and self assessment opportunities and scaffold the development of collaborative skills and feedback literacy.	Connectivity: Student empowerment, choice, and peer learning should feature as a quality indicator on program evaluation to indicate the extent to which students feel supported and able to take ownership of their learning. --- Tip: When implementing appropriately scaffolded peer learning and self regulation, compare the evaluation data with past evaluations to identify positive impact. --- Example: Students could lead evaluation focus groups and co-design parts of the curriculum, or even co-teach sessions.
Opportunities for students to relate course content to their own experiences, encouraging the sharing of diverse perspectives and interpretations. (5/8)	Connectivity: Creating space for faculty to be open and honest with their own teaching skill gaps allows staff to speak from their own perspectives, and work together in a form of mutual trust and transparency to develop professionally. --- Tip: It may be safer to share perspectives within a smaller group, such as a school or department. --- Example: Use an ePortfolio and encourage staff to showcase their own skill gap identification and development, and use this faculty ePortfolio to showcase growth.	Connectivity: Relating the assessment topic to a student's own experience or goals for future practice is commonly incorporated into, and integral for, many assessment tasks. --- Tip: Students may not know innately how to articulate their experiences, and this is best elicited through a deeply considered questioning framework. --- Example: ePortfolios, case study reflections, critical reflections and work integrated learning workbooks all require students to draw on their own lived experiences in relation to the course content.	Connectivity: These standards are inherently connected as it is through the articulation of the students' lived experience of the program that the program should be evaluated. --- Tip: Feedback from a single student that differs from the group's majority opinion may represent a marginalized group and should not be dismissed due to its lack of numerical representation. --- Example: Organise focus groups of students that represent diversity in their experience to unpack their experiences on a deeper level than survey evaluation allows, and acknowledge that a student voice is inherently representative.
Opportunities for students to work interactively in diverse and mixed groups. (6/8)	Connectivity: Faculty teaching competency is essential, particularly in understanding the nuances of different cultures, genders, ages, religions and ethnicities and how to facilitate opportunities for diverse students to work interactively. --- Tip: A fundamental aspect of considering diversity is developing a self-awareness of faculty's own perspectives, biases, and prejudices. --- Example: Consultation with diversity experts within is critical in this space. Leverage internal professional development opportunities that speak to cultural humility, reflecting on internal biases and fostering empathy.	Connectivity: Group project-based assessments foster collaboration, inter- and intra-personal skills, and, if appropriately scaffolded, promote diverse thinking while mirroring real-world engineering practice. --- Tip: Scaffold group assessments with a co-created group contract outlining expectations, ways of working, and conflict management strategies. --- Example: Create a group assessment task where student groups are formed based on their interest in a topic. This can help transition students into diverse working groups by leveraging a shared interest or experience.	Connectivity: The diversity of student groups depends largely on recruitment processes. Evaluation is a critical time to identify where marginalised groups could be more inclusively recruited from secondary education. --- Tip: Lead by example in this pace by ensuring there is diversity in the faculty. --- Example: During the evaluation, use student demographic data safely in line with inclusive practices and data protection policies to inform student recruitment decisions.
Integration of themes of equality, diversity and inclusivity into learning materials and activities. (7/8)	Connectivity: EDI principles and good practice in educational design intersect significantly, so by embedding EDI themes into the curriculum, faculty can leverage the efficiency of this overlap when considering professional development. --- Tip: Embedding EDI practice in the learning materials and activities will also help faculty to be aware of any marginalisation their own colleagues experience. --- Example: Partner with EDI industry organisations (for example, Diversity Council Australia (https://www.dca.org.au/)) for development opportunities, particularly in smaller institutions where central teams have reduced capacity.	Connectivity: Students can be exposed to EDI themes through learning assessment and its modality, as well as the support and preparation resources aligned with the assessment. --- Example/Tip: When providing choice in assessment, integrate a rationale component that asks the student whether their choice is related to the existing knowledge base or their aligned interests. Have students reflect on whether their choice is related to improving their diversity of thought.	Connectivity: Program evaluation is a critical time to evaluate the inclusion of EDI theme integration and whether these are appropriately and adequately integrated across the curriculum. --- Tip: In creating evaluative surveys, be clear in how you define EDI themes. This will enhance EDI literacy as the stakeholder may not hold the same knowledge and there may be miscommunication if there is a lack of specificity. --- Example: During program evaluation, EDI-specific questions and checklists can be designed to seek feedback from key stakeholders.
Accessible learning materials and resources available to students in advance of curriculum delivery. (8/8)	Connectivity: Faculty workload demands are systematically high, so to enable them to provide accessible resources before curriculum delivery, there must be flexibility in deadlines, a focus on working one semester ahead, and a reduction in administrative tasks that hinder faculty capacity. --- Tip: Capacity, capability and competence are tightly connected. Without capacity, educators cannot develop capability or competence. --- Example: Training and development programs on creating accessible resources should be conducted a minimum of 12 months in advance of curriculum delivery to allow faculty to implement the practice well in advance of curriculum delivery.	Connectivity: Learning assessment is commonly provided well in advance of curriculum delivery as a result of the regulatory requirements of most institutions. However, this may often be presented as a form and concept that shows constructive alignment, not a fully fleshed-out assessment task. --- Tip: Keep all assessment information in one location on the learning management system, including documents, forums and recordings. --- Example: Ensure the assessment task type and critical assessment information are available in the handbooks, and release all assessment information that is not time-sensitive at the beginning of the semester.	Connectivity: Feedback on student perspectives of accessible resources given in advance of the curriculum can provide evidence for the positive impact that can be showcased across the faculty. --- Tip: Consult with your EDI experts to construct safe questions around ideas like stress and anxiety. --- Example: Add questions to student evaluation that elicit perspectives on the early release of accessible resources. Questions like "How did receiving the resources early affect your preparation for the course and the assessment? What impact did this have on your stress and anxiety levels?

APPENDIX: PART 3A (OF 5) ASSESSMENT & FEEDBACK MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (1-3)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 1: Context	Standard 2: Learning Objectives	Standard 3: Integrated Curriculum
A range of assessment approaches that are accessible, non-discriminatory and timely. (1/8)	Connectivity: The variety of tasks in each stage of the CDIO program can be assessed in ways that allow students to leverage their strengths while collaborating in a team. Tip: Promote inclusive teamwork by helping students recognise each team member's strengths and provide opportunities for timely, respectful feedback. Example: In a team setting, students can select from a range of projects that accommodate different assessment approaches.	Connectivity: Program learning outcomes are aligned with institutional vision and mission, with proficiency levels set for each outcome. --- Tip: Assessment approaches must reflect the values of inclusivity, fairness, and effectiveness. --- Example: A variety of accessible and non-discriminatory assessments allows students to demonstrate proficiency at the levels set for each program learning outcome while supporting the institution's broader goals.	Connectivity: An integrated curriculum inherently facilitates diverse assessment options, increasing accessibility by enabling more students to play to their strengths. --- Tip: Educators can gather comprehensive evidence of students' skills development across multiple dimensions through various assessment types. Furthermore, timely feedback from these assessments is crucial for enhancing learning and refining personal and professional skills. --- Example: Include practical projects, collaborative tasks, reflective journals, and peer evaluations
A range of feedback approaches that are accessible, interactive, ongoing and timely. (2/8)	Connectivity: A variety of feedback approaches supports students' ongoing improvement through the CDIO process. --- Tip: Feedback should be captured right away, as it can easily be forgotten. Use tools like speech-to-text apps on your phone to capture the ideas instantly. --- Example: In the Design phase, incorporate verbal peer feedback to diversify the types of feedback students can access, alongside written educator feedback for consistency.	Connectivity: Achievement of program learning outcomes is defined in assessment, and the student's ability to achieve the learning outcomes can be supported through multiple feedback approaches. --- Tip: Reduce the feedback burden on educators through student self-assessment of the learning outcomes. --- Example: Support process-based achievement of learning outcomes through plan/draft/final assessment submissions, incorporating ongoing approaches throughout the process, and offer summative criteria that assess the students' ability to apply feedback through the process	Connectivity: Students may struggle to identify their own skill gaps. Ongoing feedback throughout the curriculum provides clear evidence of improvement over time and offers timely intervention when skills are lacking. --- Tip: Refer students to the academic skills centre when a skill weakness is identified. --- Example: Universities can seem disconnected from industry if not explicitly aligned. Align feedback recommendations with career-focused skills, such as those in Young Engineers CPD Series. https://yea.engineersaustralia.org.au/YEACPDseries
Incorporation of student choice in assessment practices. (3/8)	Connectivity: Student choice in assessment practices is innately supported throughout the entire CDIO process and context. --- Tip: Make clear the situations where students have full autonomy over their choices. --- Example: Assessment tasks based on the CDIO process provide students with extensive choice, even when the overall topic or concept is fixed..	Connectivity: While learning outcomes are fixed for accreditation purposes, students will have opportunities to choose how to achieve the learning outcomes through assessment practices. --- Tip: Learning outcome verbs such as 'select', 'choose', or those within the 'create' level of thinking inherently provide choice. --- Example: Create assessment tasks that require students to select and use appropriate programming to solve engineering problems.	Connectivity: While students benefit from autonomy, this should be guided by choices available to them in industry, as informed by internal and external stakeholders --- Tip: Offer case studies that showcase the choices generally available within the industry. --- Example: If an assessment task requires students to address an industry standard issue, allow students to select the most relevant standard for their future careers (e.g., state, national, or home country standards).of their home country).
Opportunities to critically engage with equality, diversity and inclusivity themes in assessments that relate to real life scenarios. (4/8)	Connectivity: Integrating EDI themes into the CDIO process and aligned assessments ensures solutions are developed with a critical, comprehensive understanding of diverse stakeholder needs, perspectives, and potential impacts. --- Tip: Emphasise that inclusive design fosters innovation and efficacy --- Example: Create assessment methods that evaluate students' ability to integrate EDI principles within the CDIO process.	Connectivity: Educators can explicitly develop personal and interpersonal skills aligned with real-world applications by integrating EDI themes into learning outcomes and assessments. Simultaneously, this develops critical thinking and professional competencies. --- Tip: Integrating EDI themes into learning outcomes ensures that EDI is an integral component of skill development and professional competence, not a separate or peripheral topic. --- Example: Learning outcomes that include: analysing organisational structures, evaluating inclusion strategies, developing recommendations for systemic improvements, and reflecting on their own leadership approach.	Connectivity: The connection lies in transforming traditionally siloed academic leaning into a comprehensive, socially conscious educational experience that goes beyond traditional disciplinary boundaries. --- Tip: Students learn to critically analyse systems, services, and processes through an EDI lens. --- Example: Real-life case studies can be used to develop not just theoretical understanding but practical skills in addressing complex social challenges.
Preparation, engagement and support of students throughout the assessment process that develops their assessment literacy. (5/8)	Connectivity: The CDIO program is systematically scaffolded, inherently enhancing student assessment literacy. --- Tip / Example: Feedback in all stages of the CDIO process is key to developing capable engineers.	Connectivity: Learning outcomes are central to developing assessment literacy, as students build this literacy by understanding and working towards achieving them. --- Tip / Example: Ensure learning outcomes are grammatically simple, use clear verbs, and include only what is directly and explicitly assessed.	Connectivity: Program mapping and explicit teaching of personal and professional skills prepare, engage, and support student assessment literacy. --- Tip / Example: Map personal and professional skills throughout the program, aligning each skill with the assessment regime.
Opportunities for students to act as partners in the assessment and feedback process. (6/8)	Connectivity: Enacting feedback from student partners encourages a diversity of voices in assessment and feedback processes, supporting ongoing curriculum improvement through the CDIO framework. --- Tip: Ensure two-way feedback is embedded at all stages through the CDIO cycle to promote continuous curriculum improvement. --- Example: During the Conceive phase, elicit student feedback on the clarity of information provided and the assessment task design. Act on this feedback to improve the quality of assessment and improve student outcomes	Connectivity: Incorporating feedback from student partners about their achievement of the program learning outcomes ensures the assessment is a quality constructively aligned design. --- Tip: When redesigning or improving program learning outcomes, capture the student voice through formal surveys or by in situ feedback. --- Example: Students can be surveyed each semester on their perceptions of their own progress towards achievement of the program learning outcomes, revealing overall progression and identifying gaps.	Connectivity: Assessments evaluate students' skills but not their confidence or perceived value of the skillset. Feedback from student partners can reveal gaps in supporting skill development. --- Tip: Institutions define their own graduate skills/attributes, which can be used with student partners to identify gaps. --- Example: Organise a student focus group at the end of each year. Provide the group with the target skills and levels for that year (1st, 2nd, 3rd), and gather feedback on their confidence in those skills and their preparedness.
A programme-level approach to the design, development, understanding and coordination of assessment and feedback practices. (7/8)	**Connectivity:** CDIO is a program-level approach, and the design, development, understanding and coordination of feedback practices are unpacked in detail across the twelve standards.		
Routine monitoring, review and sharing of assessment practices that embed equality, diversity and inclusivity. (8/8)	**Connectivity:** **Will mirror rows 4 and 6.** Concepts such as monitoring, reviewing and sharing equity, diversity and inclusion in assessment practice are encapsulated in seeking feedback for evaluation and integrating EDI themes into assessment design.		

APPENDIX: PART 3B (OF 5) ASSESSMENT & FEEDBACK MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (4-6)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 4: Introduction to Engineering	Standard 5: Design-Implement Experiences	Standard 6: Engineering Learning Workspaces
A range of assessment approaches that are accessible, non-discriminatory and timely. (1/8)	Connectivity: The introductory engineering course can integrate assessments that support diverse learning needs and ensure fairness. This approach aligns with the course's focus on building technical skills, personal development, and sustainability in engineering practice. --- Tip / Example: Seek reviews from stakeholders, including students, that the assessments are accessible, non-discriminatory, and timely.	Connectivity: A curriculum with basic and advanced design-implement experiences supports progressive learning, with assessments tailored to different skill levels. --- Tip / Example: Assessments should offer flexible formats, clear rubrics, and timely feedback to ensure accessibility, fairness, and equitable opportunities for all students to succeed and improve.	Connectivity: Engineering learning workspaces support all aspects of digital, hands-on, knowledge, and skills learning. --- Tip / Example: Integrating physical and digital learning environments enhances the learning experience and ensures assessments are accessible, varied, and timely, catering to diverse student needs. This supports non-discriminatory assessment practices by offering flexibility in how students engage with the material and demonstrate their learning.
A range of feedback approaches that are accessible, interactive, ongoing and timely. (2/8)	Connectivity: Students enter the introductory course predominantly from schooling where feedback is frequent, and progress is scaffolded throughout the student journey. While the same level of feedback is not possible in a University context, similar approaches can be implemented in a less time-intensive way. --- Tip: Provide varied feedback approaches in the early years to ease the transition into the introductory course, while also scaffolding self-assessment skills for later years. --- Example: Offer a pre-semester fundamental skills course that gives students safe formative feedback and a scaffolded start to their course.	Connectivity: A range of feedback approaches supports students' iterative design-implement experiences and promotes early success. --- Tip: Incorporate a criterion in the assessment task on enacting feedback to increase feedback literacy. --- Example: Provide early verbal feedback during the concept stages to address major issues before the students' full-scale design.	Connectivity: Workspaces can be leveraged to allow for different feedback modalities. --- Tip: Enhance peer feedback literacy through a simple rubric and regular active learning feedback check-ins. --- Example: Text-based formal feedback can be provided on the online learning platform, peer feedback through active learning physical spaces, and direct individual verbal feedback is most valuable in hands-on practical workspaces and laboratory environments.
Incorporation of student choice in assessment practices. (3/8)	Connectivity: Assessment choice is possible at all course levels, even in the introductory course. --- Tip: Begin with simple assessment choices where outcomes are limited to a few parameters to avoid overwhelming students in the introductory course. --- Example: Design assessment tasks that require students to select and apply programming techniques within a predefined range to scaffold their learning.	Connectivity: Student choice in assessment practices is innately supported through design-implement experiences. --- Tip: Offer common outcomes from past design-implement experiences so students are better placed to make informed choices. --- Example: Assessment tasks based on the design-implement experiences offer extensive student choice opportunities through innate design choices.	Connectivity: Students should be able to select the appropriate engineering workspaces for their assessments. --- Tip: If students are not able to access specialist laboratories outside tutorial hours, consider allocating in-class time for assessments to offer workspace choices. --- Example: Biomedical engineering labs require specific inductions and controlled use. Incorporating assessments during class time in these spaces allows students more supported choices of workspace.
Opportunities to critically engage with equality, diversity and inclusivity themes in assessments that relate to real life scenarios. (4/8)	Connectivity: Embedding EDI themes into the introductory course framework allows students to develop foundational technical skills while cultivating a socially aware, inclusive professional mindset from the start of their academic journey. --- Tip: Scaffold EDI knowledge by providing an annotated model assessment task that unpacks the themes' context and broader impact. --- Example: Task students with developing a water filtration system that requires researching water access challenges in diverse global communities, considering cultural and economic constraints, and evaluating how proposed solutions might affect different population groups.	Connectivity: Integrating EDI themes into design-implement experiences produces students who are technically proficient and socially responsible. --- Tip: This approach transforms engineering education from a purely technical discipline to a socially responsive practice that values diversity, equity, and inclusive innovation. --- Example: Students design a public transportation system that analyses accessibility for those with disabilities, considers the needs of different equity groups, evaluates the system's impact on various community demographics, and proposes inclusive design solutions that address potential barriers.	Connectivity: The physical and digital learning infrastructure can be a practical space for exploring EDI principles. The design of spaces can reflect a commitment to EDI, serving as both a functional and implicit assessment of diversity and inclusion. --- Tip: Configure assessments in laboratories, classrooms, and digital spaces to support diverse learning abilities, accessibility needs, and collaborative approaches reflective of real-world practice. --- Example: Design assessments where students analyse the laboratory and classroom layouts that accommodate various learning abilities.
Preparation, engagement and support of students throughout the assessment process that develops their assessment literacy. (5/8)	Connectivity: The CDIO program is systematically scaffolded, inherently enhancing student assessment literacy. --- Tip / Example: Feedback in all stages of the CDIO process is key to developing capable engineers.	Connectivity: The design-implement experience is scaffolded through a progression from simple to complex tasks throughout the program. --- Tip/Example: Clearly outline the elements of the design-implement experience that progress from simple to complex to provide clarity for students.	Connectivity: Using real-world workspaces, laboratories, and engineering tools provides a solid platform for students to build foundational engineering skills required for their assessment. --- Tip/Example: Use both physical and virtual spaces to foster two-way communication and collaboration among students, enhancing assessment literacy.
Opportunities for students to act as partners in the assessment and feedback process. (6/8)	Connectivity: The introductory course builds a foundation of skills and knowledge that prepares, engages and supports student assessment literacy. --- Tip / Example: The introductory course should introduce and explicitly teach the assessment formats and design elements used throughout the program.	Connectivity: The design-implement experiences are regularly evaluated and revised based on feedback from students. --- Tip: Use early semester feedback mechanisms so that students feel more agency when their feedback improves the course's current iteration. --- Example: Assist students identify skill and knowledge gaps during the design-implement process, allowing these gaps to shape the course's early stages.	Connectivity: Students offer direct experiences and perceptions of engineering workspaces and laboratories. --- Tip: When entering a new space at the beginning of the course, run a brief induction to help students feel comfortable and understand the expectations of the space (physical or virtual). --- Example: Involve student partners in the workspace evaluation group to share their experiences and offer recommendations.
A programme-level approach to the design, development, understanding and coordination of assessment and feedback practices. (7/8)	**Connectivity:** CDIO is a program-level approach, and the design, development, understanding and coordination of feedback practices are unpacked in detail across the twelve standards.		
Routine monitoring, review and sharing of assessment practices that embed equality, diversity and inclusivity. (8/8)	**Connectivity:** **Will mirror rows 4 and 6.** Concepts such as monitoring, reviewing and sharing equity, diversity and inclusion in assessment practice are encapsulated in seeking feedback for evaluation and integrating EDI themes into assessment design.		

APPENDIX: PART 3C (OF 5) ASSESSMENT & FEEDBACK MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (7-9)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 7: Integrated Learning Experiences	Standard 8: Active Learning	Standard 9: Enhancement of Faculty Competence
A range of assessment approaches that are accessible, non-discriminatory and timely. (1/8)	Connectivity: Evidence shows the impact of implementing integrated learning experiences based on the curriculum plan. --- Tip / Example: Using diverse assessment methods (e.g., projects, presentations, peer reviews) ensures students are evaluated on both disciplinary knowledge and practical skills. Timely, accessible, and non-discriminatory assessments offer continuous feedback, supporting development and ensuring equitable opportunities for success.	Connectivity: There is documented evidence that the CDIO principle is the context of the engineering program and is fully implemented. --- Tip / Example: The documented implementation of the CDIO framework in the engineering program forms a strong foundation for inclusive, accessible, and timely assessment practices. By aligning assessment with the CDIO cycle, students are evaluated on both their theoretical understanding and practical application in diverse and non-discriminatory ways, ensuring equitable opportunities to demonstrate their learning and skills.	Connectivity: Faculty competence in disciplinary knowledge and personal, interpersonal, product, process, system, and service building skills are regularly evaluated and enhanced where appropriate. --- Tip / Example: Regular faculty evaluation, ensuring both disciplinary knowledge and broader skills are continuously developed. These assessments, such as peer reviews, feedback, and professional development programs, are designed to be inclusive, offering clear and fair criteria. They provide actionable, timely feedback that supports faculty growth in areas like teaching, interpersonal skills, and service building, fostering continuous improvement across all competencies.
A range of feedback approaches that are accessible, interactive, ongoing and timely. (2/8)	Connectivity: Integrating and scaffolding student skill development within specific learning activities and assessment tasks creates space for skill development through a range of feedback mechanisms. --- Tip: Consider the fundamental skill competency level when giving feedback from integrated learning experiences. --- Example: Allow debriefing and reflection after skill-based activities: debriefing provides feedback, while reflection encourages self-assessment.	Connectivity: Active learning involves student problem-solving, investigation, and discussion, with a strong focus on educational debriefs to provide feedback, correct misconceptions, and consolidate knowledge. --- Tip: In an activity debrief, verbally indicate, “This is feedback for the whole group”, as students with low feedback literacy will not know something is feedback unless explicitly stated. --- Example: Provide a model answer with feedback annotations to specific problems to indicate an appropriate industry standard.	Connectivity: Faculty members should offer quality disciplinary feedback through various approaches, fundamental support, and a baseline of competency expectations in relation to feedback quality to be determined. --- Tip: Investigate industry-based improvement and professional development programs to identify a baseline of disciplinary feedback approaches. --- Example: Connect with industry partners and employ guest lecturers to showcase an industry standard for feedback approaches.
Incorporation of student choice in assessment practices. (3/8)	Connectivity: Students can be offered assessment choices by choosing the skills to focus on in the integrated learning experience. --- Tip: Students may benefit from selecting the skill set for the final product in areas where they struggle to meet learning outcomes. --- Example: Offer choice in the final product format for the assessment. An oral presentation can showcase communicative skills, while a written report can demonstrate argumentation and paragraph flow.	Connectivity: Active learning inherently allows students choice. For assessment practice, active learning is often represented through group or pair assessment tasks, so student choice can be made possible by selecting groups and assessment topics. --- Tip: Existing ‘norms’ may influence group or topic selection. Scaffolding students through the group formation process can help students better establish a common norm. --- Example: Offer students a choice of topic for the assessment task and allow them to select their own groups.	Connectivity: Faculty competence strongly impacts student assessment choices, as they require support to manage and facilitate the wide range of options available to students. --- Tip: Faculty need to be comfortable with students choosing assessments outside the educator’s discipline, moving into more interdisciplinary spaces. --- Example: Allocate time within interdisciplinary meetings for faculty to discuss challenges they have encountered with supporting student choice.
Opportunities to critically engage with equality, diversity and inclusivity themes in assessments that relate to real life scenarios. (4/8)	Connectivity: Feedback from student partners can identify where integrated learning experiences are having less impact than envisaged. --- Tip: Increase the students' feelings of empowerment by eliciting feedback after key integrated learning experiences, making suitable adjustments, and informing them of the adjustments that have been made. --- Example: Offer student cohorts choice in relation to the integrated learning experiences and capture their feedback from those experiences to implement in the next experience cycle.	Connectivity: By using active learning methods, like group assessment, debate and discussion tasks, the student can critically examine EDI themes as they relate to their personal and group realities. This moves beyond theoretical discussions to concrete, lived experiences in the moment. --- Tip: Develop empathy through perspective-taking exercises and reflective post-assessment debriefs. --- Example: Create a group assessment task with an individual reflective component that encourages personal reflection on social identities and power dynamics.	Connectivity: Embedding EDI themes into assessments encourages faculty to expand their understanding and teaching of engineering and how it intersects with diverse perspectives and inclusive practices. --- Tip: Integrate EDI themes as an aspect of the hidden curriculum and align them with graduate attributes to emphasise their foundational role in fostering a more inclusive engineering curriculum. --- Example: Map EDI-themed assessments across the course and identify gaps to target educators who need additional support.
Preparation, engagement and support of students throughout the assessment process that develops their assessment literacy. (5/8)	Connectivity: Teaching personal and professional skills through hands-on learning experiences prepares, engages, and supports student assessment literacy. --- Tip/Example: During integrated learning experiences, provide a debrief with an expert response to help students identify knowledge and skill gaps and plan to address them before formal assessment submission.	Connectivity: The hands-on, interactive social learning provided through active learning prepares students for individual and team assessment and develops assessment literacy. --- Tip/Example: Allocate class time for activities that align with assessment task outcomes.	Connectivity: Faculty competence refers to supporting students in understanding the relevant disciplinary fundamentals better. This deeper learning in a formative environment better supports students' progress towards summative assessment literacy. --- Tip/Example: Offer examples of faculty skill development over time and lessons learnt through experience, as this can break down faulty-student barriers and support student engagement with the assessment.
Opportunities for students to act as partners in the assessment and feedback process. (6/8)	Connectivity: The link between these concepts is a pedagogical strategy that views learning as a multidimensional process, recognising that skill development is inseparable from understanding social contexts and human diversity. --- Tip: By integrating technical skills with social awareness, students are prepared to create more comprehensive solutions and understand the broader impact of their work. --- Example: Create an assessment task that gets students to analyse systemic barriers within their discipline.	Connectivity: Active learning puts students at the centre of the experience, engaging in the experience rather than being the recipient of knowledge transfer. The teaching dynamic becomes one of partnership rather than the keeper of knowledge. --- Tip: Give students quiet individual time to process ideas before being exposed to the ideas and opinions of their peers and educators. Active learning does not mean always talking. --- Example: Offer a series of problems for groups to solve, but also allow students to choose to investigate alternatives.	Connectivity: Gaps in faculty disciplinary competency may be revealed through activities aligned with students as partners. --- Tip: Near peers in the early years are effective for identifying faculty gaps in disciplinary competence, often through indications of skill and knowledge gaps or significant jumps in expectations between units or semesters. --- Example: For contextualised student feedback, run a student focus group that elicits feedback broadly to highlight potential faculty disciplinary gaps, rather than individual educator gaps.
A programme-level approach to the design, development, understanding and coordination of assessment and feedback practices. (7/8)	**Connectivity:** CDIO is a program-level approach, and the design, development, understanding and coordination of feedback practices are unpacked in detail across the twelve standards.		
Routine monitoring, review and sharing of assessment practices that embed equality, diversity and inclusivity. (8/8)	**Connectivity:** **Will mirror rows 4 and 6.** Concepts such as monitoring, reviewing and sharing equity, diversity and inclusion in assessment practice are encapsulated in seeking feedback for evaluation and integrating EDI themes into assessment design.		

APPENDIX: PART 3D (OF 5) ASSESSMENT & FEEDBACK MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (10-12)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 10: Enhancement of Faculty Teaching Competence	Standard 11: Learning Assessment	Standard 12: Program Evaluation
A range of assessment approaches that are accessible, non-discriminatory and timely. (1/8)	Connectivity: Faculty teaching competence is regularly evaluated and updated as needed. --- Tip / Example: Faculty experienced in designing integrated, active, and experiential learning experiences are likely to create assessments that reflect this diversity. These can include collaborative projects and hands-on tasks, allowing students to demonstrate knowledge in various ways. Using diverse assessment methods ensures all students, regardless of learning preferences, have opportunities to succeed. Furthermore, embedding timely feedback and using multiple assessment points throughout the learning process supports continuous improvement.	Connectivity: Quality learning assessment standards prioritise real-world, authentic and varied assessment approaches that can inherently and systematically align with the range of assessment approaches. --- Tip / Example: Do this in a way that works for all your students. Otherwise, it is only a measure of some, not all, students' abilities. You could have student groups regularly review the quality and availability of methods of feedback gained through assessments.	Connectivity: Reviewingthe range and accessibility of assessment is vital to understanding how/why students have/have not met learning outcomes, and what may need to change. --- Tip / Example: Colour-code the assessment approaches to highlight the variety (or lack of) approaches to assessment.
A range of feedback approaches that are accessible, interactive, ongoing and timely. (2/8)	Connectivity: Faculty members should offer quality educational feedback through diverse approaches, fundamental support, and clearly defined competency expectations. --- Tip: Most institutions have faculty-based Educational/Learning Designers that are experienced and qualified to provide feedback and can be leveraged for support. --- Example: Ensure the faculty/institution has a clear and informative professional development program on feedback.	Connectivity: Student groups regularly review the quality and availability methods of feedback gained through assessments. --- Tip: Assessment-based feedback is usually the most accessed and easily understood by students, so student feedback literacy is usually higher in this space. --- Example: Set a maximum volume of feedback per assessment: Students will often want large volumes of feedback, but this is usually counterproductive. The more feedback given, the less likely the student is to enact the feedback.	Connectivity: Student progress based on feedback provides evidence for continuous course improvement. --- Tip: Ensure you seek permission from specific students when capturing and documenting their progress for use in course review or accreditation. --- Example: Documented samples of student development based on feedback can support continuous improvement across year levels.
Incorporation of student choice in assessment practices. (3/8)	Connectivity: Faculty teaching competence heavily impacts student choice of assessment. There may be a reliance on traditional forms of assessment that allow educators to control all aspects of the assessment and a reluctance to let go of this control. ---------- Tip: Faculty need to be made comfortable with the idea that they are also not required to be educational experts in every possible outcome and will need to be seen as a guide on the side. --- Example: Promote and showcase educators who lean into the unknown, developing additional knowledge and skill sets as a result of the student's assessment choices.	Connectivity: Both summative and formative learning assessment methods can integrate student choice in assessment, improving self-efficacy and enhancing critical thinking. --- Tip: Scaffold student choice in summative assessment by introducing student choice in formative assessment. --- Example: Allow students to formatively self-assess based on learning outcomes and set goals for improvement.	Connectivity: Student choice in assessment improves student agency, leading to positive program evaluations. --- Tip: Gather feedback to explore whether assessment options contributed to students feeling under-supported, and how. --- Example: Capture student feedback when assessment design relies heavily on student choice.
Opportunities to critically engage with equality, diversity and inclusivity themes in assessments that relate to real life scenarios. (4/8)	Connectivity: Embedding EDI themes into assessments helps faculty recognise how inclusive engineering design principles align with inclusive education. --- Tip: Collaborate with faculty to develop assessment strategies that align with both inclusive practices and industry-relevant skills --- Example: Provide training on designing inclusive assessments that incorporate real-world scenarios related to equality, diversity, and inclusivity	Connectivity: Effective assessment uses a variety of methods aligned with learning outcomes that address disciplinary knowledge and skills. This alignment directly impacts students' progress and engagement through the assessment. --- Tip / Example: Increase incentive for engagement tasks by describing how the learning tasks explicitly align to the assessment tasks.	Connectivity: Stakeholder input and evaluation provide a multi-perspective approach to understandin g and implementing the CDIO process and EDI principles. --- Tip: Incorporate EDI-specific assessment standards across the program and seek feedback from key stakeholders. --- Example: Create an evaluation of the assessment tasks that asks students whether their diverse perspectives were represented in the task.
Preparation, engagement and support of students throughout the assessment process that develops their assessment literacy. (5/8)	Connectivity: Faculty teaching competence influences student preparation by explicitly teaching skills and knowledge, which scaffolds students' assessment literacy development. --- Tip / Example: the institutional student skills/academic skills development team is a wealth of information for scaffolding assessment literacy.	Connectivity: Effective assessment uses a variety of methods aligned with learning outcomes that address disciplinary knowledge and skills. This alignment directly impacts students' progress and engagement through the assessment. --- Tip / Example: Increase incentive for engagement tasks by describing how the learning tasks explicitly align to the assessment tasks.	Connectivity: Assessment outcomes are a key feedback measure for program evaluation. Where failure is present, an analysis must be conducted to determine whether this is linked to a lack of scaffolding and preparation or by some other factor. --- Tip / Example: Elicit feedback from students outside of the institutional evaluation process to address assessment scaffolding issues that may be present.
Opportunities for students to act as partners in the assessment and feedback process. (6/8)	Connectivity: Gaps in faculty teaching competency may be identified through activities aligned with students as partners. --- Tip: While gaps in faculty competency can be indicated by students, its advisable to be careful about the information elicited through institution-wide student satisfaction surveys. --- Example: For contextualised student feedback, run a student focus group that elicits feedback broadly to indicate potential faculty education gaps rather than individual educator gaps.	Connectivity: Student partners regularly review the use of learning assessment methods and make recommendations for continuous improvement. --- Tip: Students may express what they want in assessment, but educators will always be the driving force of what students need in assessment. --- Example: Co-create assessment tasks and rubrics to increase student agency. Provide students with a basic concept of the task, then develop the details together. Educators will guide the criteria, but co-creating rubrics helps students understand their design and purpose.	Connectivity: Evidence is captured from student focus groups and students as partner initiatives, with documented changes that have been implemented as a result of the students' voice. --- Tip: Student agency comes from enacting student feedback, not just listening to it. --- Example: During a course review and accreditation cycle, submit documentation that captures the changes made as a result of student-led initiatives.
A programme-level approach to the design, development, understanding and coordination of assessment and feedback practices. (7/8)	**Connectivity:** CDIO is a program-level approach, and the design, development, understanding and coordination of feedback practices are unpacked in detail across the twelve standards.		
Routine monitoring, review and sharing of assessment practices that embed equality, diversity and inclusivity. (8/8)	**Connectivity:** **Will mirror rows 4 and 6.** Concepts such as monitoring, reviewing and sharing equity, diversity and inclusion in assessment practice are encapsulated in seeking feedback for evaluation and integrating EDI themes into assessment design.		

APPENDIX: PART 4A (OF 5) LEARNING ENVIRONMENT MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (1-3)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 1: Context	Standard 2: Learning Objectives	Standard 3: Integrated Curriculum
Assurance that all physical and virtual learning spaces are accessible, flexible and, where appropriate, reflective of student diversity. (1/7)	Connectivity: Understanding the implications of technology on social factors/society requires students to hear voices different from their own. Diversity among peers is therefore essential, and the learning environment must enable participation from a diverse student body. --- Tip: Create non-verbal communication channels (e.g., post-its, chat functions) to allow more students to participate. This supports Universal Design for Learning by offering multiple means of communication. --- Example: Students work in groups with a client brief and discuss the product's social implications through verbal and text-based discussions. One student ensures inclusive participation by checking in with quieter members and reading out their input.	Connectivity: All interpersonal learning outcomes (for example cross-cultural competency) depend on a diversity of peers, as students will encounter that diversity as they enter the workforce. --- Tip: Consider the general diversity of the country and what skills and knowledge students would need to effectively collaborate and communicate within that context. --- Example: Learning outcomes are clear, short, grammatically simple and reflect real-world diversity.	Connectivity: Connected because the context (standard 1) and learning outcomes (standard 2) are connected --- Tip: When mapping learning outcomes to activities, consider whether the activity design will actually be accessible to ensure a diversity of student experiences will be present. --- Example: Curriculum-wide LMS accessibility compliance is systematically applied to all subjects.
Utilisation of physical learning spaces to facilitate student access to and engagement with the curriculum. (2/7) Utilisation of virtual learning spaces to facilitate student access to and engagement with the curriculum. (3/7)	Connectivity: At a contextual level, the physicality or virtuality of a learning space is relevant in that participating in the CDIO process can occur through both, and the artefacts generated can apply to both virtual and physical settings --- Example: Learning in both physical and virtual spaces allows students to consider and experience design needs for both formats.	Connectivity: The skills students need to develop may require working with peers, key technologies and systems, etc. and practising these skills authentically may require a mix of learning spaces. This may have a role in Standard 2 (learning outcomes) developing learning outcomes but is certainly required in Standard 3 (Integrated curriculum) planning how to integrate them through a sequence of activities. --- Tip: Consider which skills and knowledges are best cultivated through physical, virtual or a mix of both spaces. --- Example: A need can be identified for expertise with practices and tools like 3D printing, AutoCAD, etc. Developing competency with 3D printing is likely best physically; however, AutoCAD may be easier to do virtually if working in groups.	Connectivity: The skills students need to develop may require working with peers, key technologies and systems, etc. and practising these skills authentically may require a mix of learning spaces. This may have a role in Standard 2 (learning outcomes) developing learning outcomes but is certainly required in Standard 3 (Integrated curriculum) planning how to integrate them through a sequence of activities. --- Tip: Consider which skills and knowledges are best cultivated through physical, virtual or a mix of both spaces. --- Example: A need can be identified for expertise with practices and tools like 3D printing, AutoCAD, etc. Developing competency with 3D printing is likely best physically; however, AutoCAD may be easier to do virtually if working in groups
Utilisation of accessible learning resources and technologies to enable student access to and engagement with the curriculum. (4/7)	Connectivity: Full engagement in the curriculum for all students will allow participation in the CDIO processes, contributing to the development of modern engineering solutions. To adopt this as the context consistently, it needs to be accessible for all students to engage with that context, not just some.	Connectivity: These two standards do not have to intersect, but they may. Accessibility of the materials level can be designed regardless of the learning outcomes developed. --- Tip: Ensure the language and grammar used within the learning outcomes are plain and unambiguous to improve comprehension and accessibility for all students. --- Example: Get feedback on learning outcomes from educational designers, language support groups and discipline leads.	Connectivity: Without accessible learning resources and technologies, some students might only partially access certain aspects of the curriculum, limiting their ability to develop the complete skill set needed for their future careers. --- Example: A near-peer program across the year levels assists students in connecting with the curriculum in a student-centred and supportive way.
Provision of additional/ alternative learning resources and technologies where required to support access to and engagement with the curriculum. (5/7))	Connectivity: Will mirror row 4. The difference between 4 and 5 in Advance HE EDI learning environments is between the universal level of support and specialised student support. Both are essential for curriculum accessibility.		
Liaison with internal learning partners to ensure learning spaces, resources, delivery and support reflect the programme's approach to EDI in the curriculum. (6/7)	Connectivity: Reviewing the accessibility of space, resources, and delivery is essential to implementing the practices well, and the rows above explain why these are linked with the relevant CDIO standards		
Liaison with external learning partners to ensure learning spaces, resources, delivery and support reflect the programme's approach to EDI in the curriculum. (7/7)	Connectivity: Will mirror row 6. The difference between 6 and 7 in Advance HE EDI learning environments is the partner participating in the process, and this requires internal and external partners to incorporate both institutional knowledge and a layer of separation around any perception of bias or conflict of interest.		

APPENDIX: PART 4B (OF 5) LEARNING ENVIRONMENT
MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (4-6)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 4: Introduction to Engineering	Standard 5: Design-Implement Experiences	Standard 6: Engineering Learning Workspaces
Assurance that all physical and virtual learning spaces are accessible, flexible and, where appropriate, reflective of student diversity. (1/7)	Connectivity: The requirement of developing initial interpersonal skills and attitudes is particularly important early as some students may enter their course from quite homogenous schooling experiences and may be underprepared for the diversity and richness of human experience and how to communicate and collaborate effectively and respectfully around this. --- Tip: For introductory subjects, more scaffolding and guidance will be required in how to communicate and collaborate across diverse cohorts, and students will have less developed self-management skills (especially emotional regulation), which will need extra support. --- Example: Students are taught early about the variety of social conventions both across and within cultures, neurotypes, etc., to prepare them for effective cross-cultural group work.	Connectivity: Sustainable and fit-for-purpose development requires that products and processes meet the true needs and can be maintained over time; this requires insights into the diversity of possible users and implementers, which is only possible with a diversity of peers and/or inviting external people who can contribute lived experience. --- Tip: Ensure students have access to experiences of real end users, whether within the class cohort or as externals invited into the space. --- Example: Students are developing a software tool for coordinating in-home care, as such, they need to know how disability support workers, disabled folks, and their families would experience such a system.	Connectivity: Hands-on learning may assume certain levels of mobility and physical dexterity, which may differ over a population. Alternatives must be provided to ensure all students can participate. --- Tip: A proactive design (for example Universal Design for Learning) will always be better than making adjustments later, as many students may be hesitant to disclose their needs. Occupational therapists can be consulted to assist in identifying alternatives and supports for a variety of individual needs. --- Example: Students are expected to use a 3D printer for their wing designs to assess aerodynamicity. The 3D printer requires reaching from an average standing height, meaning (for instance) wheel-chair users are unable to participate.
Utilisation of physical learning spaces to facilitate student access to and engagement with the curriculum. (2/7) Utilisation of virtual learning spaces to facilitate student access to and engagement with the curriculum. (3/7)	Connectivity: In order to build and strengthen student motivation and develop the early skills required to succeed over their course, the barriers posed by different learning spaces need to be considered. Otherwise, students may get discouraged and give up thinking Engineering as a field is not for them. --- Tip: Provide multiple modalities for participating; where this is not possible, make it clear why the selected mode is essential to the skills and knowledge involved. --- Example: A student with depression may find it considerably harder to join physical classes and may not be comfortable being seen during a depressive episode but may still be able to participate in online classes.	Connectivity: As with (2) and (3), the skills and knowledges being developed will apply in both physical and virtual settings, so students need opportunities to work in both formats. Equally, students for whom one modality is inaccessible will not be able to participate in design-implement activities offered in one mode only. --- Example: An ADHDer / student with ADHD may find the physical presence of peers around them essential to keep them engaged in the practice, especially for parts that are less aligned to their personal motivations.	Connectivity: Standard (6) is explicitly about the opportunities to engage in both physical and digital learning environments, which reflect these two rows directly.
Utilisation of accessible learning resources and technologies to enable student access to and engagement with the curriculum. (4/7)	Connectivity: The goal is to maximise engagement and set students up for success. Inaccessible learning does the opposite and excludes already marginalised students from engineering fields. --- Tip: Ensure this information is given to them right from the beginning of the introductory course. --- Example: A fundamental aspect of accessibility is ensuring students are aware of the accessible learning resources and technologies they have available to them right from the introductory course.	Connectivity:The relationship between these standards is particularly important because it creates a feedback loop: accessible education leads to engineers who understand accessibility needs, who then create more accessible products and systems for society. --- Tip: Ensure the accessibility of learning resources and technologies can manifest in different ways within design-implement experiences. --- Example: Ensure all digital content is compatible with access readers for visually impaired students, and another is the use of speech-to-text software to assist students with writing difficulties in documenting their design process.	Connectivity: Effective hands-on learning in both physical and digital spaces requires accessibility in the curriculum so they can be prepared. --- Tip: Ensuring the accessibility of learning resources and technologies can manifest in different ways within the learning space. --- Example: In physical spaces, this may mean desks and chairs that are adjustable and can be arranged to provide ample space for movement to help students with physical disabilities engage comfortably. In digital workspaces, this could mean ensuring closed captioning is available and accurate on all learning resources.
Provision of additional/ alternative learning resources and technologies where required to support access to and engagement with the curriculum. (5/7))	Connectivity: Will mirror row 4. The difference between 4 and 5 in Advance HE EDI learning environments is between the universal level of support and specialised student support. Both are essential for curriculum accessibility.		
Liaison with internal learning partners to ensure learning spaces, resources, delivery and support reflect the programme's approach to EDI in the curriculum. (6/7)	Connectivity: Reviewing the accessibility of space, resources, and delivery is essential to implementing the practices well, and the rows above explain why these are linked with the relevant CDIO standards		
Liaison with external learning partners to ensure learning spaces, resources, delivery and support reflect the programme's approach to EDI in the curriculum. (7/7)	Connectivity: Will mirror row 6. The difference between 6 and 7 in Advance HE EDI learning environments is the partner participating in the process, and this requires internal and external partners to incorporate both institutional knowledge and a layer of separation around any perception of bias or conflict of interest.		

APPENDIX: PART 4C (OF 5) LEARNING ENVIRONMENT MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (7-9)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 7: Integrated Learning Experiences	Standard 8: Active Learning	Standard 9: Enhancement of Faculty Competence
Assurance that all physical and virtual learning spaces are accessible, flexible and, where appropriate, reflective of student diversity. (1/7)	Connectivity: Much like standard 1, having access to other voices is essential to understand these implications. A truly diverse representation of voices requires accessible teaching and learning spaces. --- Tip: Engage with Universal Design for Learning to build proactively accessible experiences. --- Example: Indigenous Australians face persistent structural barriers and have often experienced the theft of Cultural Knowledge. Ensuring staff have completed Cultural Safety training and engage in practices like Acknowledgements of Country are a way of ensuring the environment is accessible for First Nations Peoples (some of whom will be students, some external stakeholders, etc.) regardless of whether the project itself has an explicit Indigenous lens.	Connectivity: The examples given in the CDIO standard align considerably with social constructivist, inquiry-based and experiential learning. As with standards 1-4 and 6, accessibility is essential to allow all students (and any external visitors) to participate. --- Tip: Educators should create diverse learning environments without expecting students to share their personal experiences. Educators can foster diversity by incorporating a variety of perspectives into active learning experiences. --- Example: Students are to debate a topic and to ensure psychological safety. A social contract is established to ensure debating is kept to the concepts without targeting individuals, as well as considering how they will enable contributions considerate of social anxiety	Connectivity: Supporting faculty competency in this space aligns well with any practices to train staff in how to make their learning spaces accessible and culturally safe, as they can then role model the skills students will need to engage across diversity. In addition, recruitment and promotion processes are reviewed to ensure there are no additional barriers in place for a diversity of staff at different levels so students can see themselves represented through their educators. --- Tip: Prioritise training of current staff first to ensure sufficient critical mass behind changes to faculty processes and structures. --- Example: Faculty competence can be enhanced through training, recruitment, and promotion, as well as role-modelling senior leaders' examples that model inclusive and accessible practices.
Utilisation of physical learning spaces to facilitate student access to and engagement with the curriculum. (2/7) Utilisation of virtual learning spaces to facilitate student access to and engagement with the curriculum. (3/7)	Connectivity: The use of physical and virtual learning spaces is relevant in the same way as (1/7). There are limits to how accessible a solely physical or solely virtual space can be.	Connectivity: As per the above. Many of these techniques are highly dependent on the space in which they are run and cannot be designed without consideration of where and when they would occur. --- Tip: Physical movement around a classroom can be productive in encouraging active thinking and exposure to a variety of views. This can be replicated in virtual spaces with careful designs. --- Example: Students are designing a structure from dry noodles to hold a certain weight. One student per team visits other teams to observe their approaches and report back to incorporate new ideas.	Connectivity: Similar to the above. Upskilling staff to ensure they can make the learning environment accessible means considering the use of both physical and virtual learning spaces. This will be directly relevant to their expertise in the discipline skills and practices within those spaces.
Utilisation of accessible learning resources and technologies to enable student access to and engagement with the curriculum. (4/7)	Connectivity: Accessible learning technologies, when thoughtfully integrated, create more opportunities for active and experiential learning by removing barriers to participation and enabling all students to fully engage in hands-on, problem-solving activities. --- Example: Learning resources within the integrated learning experiences can be developed in multiple formats of content delivery to support students according to their learning needs. For example, video demonstrations, written instructions, and interactive 3D models.	Connectivity: Accessibility is often thought of with respect to technology and resources but also applied to the ways in which students engage with these. In particular, creating flexible learning environments that accommodate individual learning differences. --- Example: When offering printed resources in active learning experiences, also give access to a digital version so that students may fully engage with that resource using whatever technology they need to support them.	Connectivity: Designing accessible learning materials requires explicit skills and training to support this. These skills are essentially about good teaching practice. These skills, however, are also dependent on the context of the learning itself, requiring a good discipline-specific skill set as well. --- Tip: Within the institution, there may be a centrally located team that has information and resources on how to provide accessible learning technology and resources for students. This team may be within a disability support centre or an equity, diversity, and inclusion team.
Provision of additional/ alternative learning resources and technologies where required to support access to and engagement with the curriculum. (5/7))	Connectivity: Will mirror row 4. The difference between 4 and 5 in Advance HE EDI learning environments is between the universal level of support and specialised student support. Both are essential for curriculum accessibility.		
Liaison with internal learning partners to ensure learning spaces, resources, delivery and support reflect the programme's approach to EDI in the curriculum. (6/7)	Connectivity: Reviewing the accessibility of space, resources, and delivery is essential to implementing the practices well, and the rows above explain why these are linked with the relevant CDIO standards		
Liaison with external learning partners to ensure learning spaces, resources, delivery and support reflect the programme's approach to EDI in the curriculum. (7/7)	Connectivity: Will mirror row 6. The difference between 6 and 7 in Advance HE EDI learning environments is the partner participating in the process, and this requires internal and external partners to incorporate both institutional knowledge and a layer of separation around any perception of bias or conflict of interest.		

APPENDIX: PART 4D (OF 5) LEARNING ENVIRONMENT MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (10-12)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 10: Enhancement of Faculty Teaching Competence	Standard 11: Learning Assessment	Standard 12: Program Evaluation
Assurance that all physical and virtual learning spaces are accessible, flexible and, where appropriate, reflective of student diversity. (1/7)	Connectivity: This standard is connected to standards 5, 7, 8, and 11, and staff need sufficient support and expertise to implement these.	Connectivity: Ensuring the spaces students learn within are accessible is essential to ensure that students can get sufficient practice, scaffolding and support to successfully complete their assessment tasks. Without access to these, students will underperform in ways that mirror existing societal barriers, stigma, and bias, and thus, assessments will become less meaningful evaluations of what students can genuinely achieve. --- Tip: Consider what students would need to fully participate in the assessment task regardless of any disadvantage they may face. --- Example: Offer flexible assessment options, such as a core concept/task and a flexible format submission that accommodates different learning abilities.	Connectivity: Some program evaluations would be performed with current students and alumni in order to ensure suitability. Depending on how a learning environment is defined, it could be argued that this standard is also aligned. --- Tips/example: Students engage in a focus group discussion within one of their subjects to evaluate the program. In this case, the focus group is occurring within a learning context, and thus accessibility and diversity within that space is essential to ensure all can participate and the evaluation of the program is complete.
Utilisation of physical learning spaces to facilitate student access to and engagement with the curriculum. (2/7)	Connectivity: This standard is connected to standards 5, 7, 8, and 11, and staff need sufficient support and expertise to implement these.	Connectivity: Assessment of learning can occur both during class time and asynchronously. In-class assessment needs to consider the use of physical and virtual space in its facilitation. --- Tip: Consider using class environments to assess the process of learning, such as through regular check-ins and observation of how students tackle a given problem.	Connectivity: Some program evaluations would be performed with current students and alumni in order to ensure suitability. Depending on how a learning environment is defined, it could be argued that this standard is also aligned. --- Tips/example: Students engage in a focus group discussion within one of their subjects to evaluate the program. In this case, the focus group is occurring within a learning context, and thus accessibility and diversity within that space is essential to ensure all can participate and the evaluation of the program is complete.
Utilisation of virtual learning spaces to facilitate student access to and engagement with the curriculum. (3/7)			
Utilisation of accessible learning resources and technologies to enable student access to and engagement with the curriculum. (4/7)	Connectivity: Designing accessible learning materials requires explicit skills and training to support this. These skills are essentially about good teaching practice. These skills, however, are also dependent on the context of the learning itself, requiring a good discipline-specific skill set as well. --- Tip: Within the institution, there may be a centrally located team that has information and resources on how to provide accessible learning technology and resources for students. This team may be within a disability support centre or an equity, diversity, and inclusion team.	Connectivity: If the curriculum is not accessible, affected students cannot be accurately assessed as it will no longer represent what they could be capable of with appropriate support. --- Tip/Example: Incorporate a mix of formative and summative assessments, such as quizzes, peer reviews, and self-assessments, that are accessible and can be made flexible to provide multiple opportunities for students to demonstrate	Connectivity: Evaluation of programs should include student voice, and if the materials are inaccessible, there will be some students who cannot evaluate the substance of the curriculum. --- Tip/Example: Ensure the course evaluation platform is compatible with screen readers and other assistive technologies so that students of all abilities can give feedback in the student evaluation of teaching surveys.
Provision of additional/ alternative learning resources and technologies where required to support access to and engagement with the curriculum. (5/7))	Connectivity: Will mirror row 4. The difference between 4 and 5 in Advance HE EDI learning environments is between the universal level of support and specialised student support. Both are essential for curriculum accessibility.		
Liaison with internal learning partners to ensure learning spaces, resources, delivery and support reflect the programme's approach to EDI in the curriculum. (6/7)	Connectivity: Reviewing the accessibility of space, resources, and delivery is essential to implementing the practices well, and the rows above explain why these are linked with the relevant CDIO standards		Connectivity: In addition to being relevant for the same reason as standards 1 through 11, standard 12 is particularly relevant given that it is around program evaluation in the first place
Liaison with external learning partners to ensure learning spaces, resources, delivery and support reflect the programme's approach to EDI in the curriculum. (7/7)	Connectivity: Will mirror row 6. The difference between 6 and 7 in Advance HE EDI learning environments is the partner participating in the process, and this requires internal and external partners to incorporate both institutional knowledge and a layer of separation around any perception of bias or conflict of interest.		

APPENDIX: PART 5A (OF 5) STAFF ENGAGEMENT
MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) STAFF ENGAGEMENT TO CDIO STANDARDS (1-3)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 1: Context	Standard 2: Learning Objectives	Standard 3: Integrated Curriculum
Engagement in and utilisation of continuing professional development in the embedding of EDI in the curriculum to enhance practice. (1/8)	Connectivity: Evaluation groups recognise that CDIO is the context of the engineering program and use this principle as a guide for continuous improvement. --- Tip/Example: Facilitate CPD initiatives that enable faculty members to collaborate on the best ways to address EDI in both theory and practice. This could include interdisciplinary initiatives that unite staff from engineering and social sciences to develop an inclusive approach to teaching sustainable engineering practices	Connectivity: Internal and external groups regularly review and revise program learning outcomes and/or program goals based on changes in stakeholder needs --- Tip: As part of CPD, staff can learn how to better incorporate feedback from a wide range of stakeholders—students, industry professionals, and community members—into curriculum design. This ensures that learning outcomes are reflective of a diverse range of perspectives and needs, which will ultimately enhance the student experience by preparing them for the global and diverse contexts in which they will operate as engineers. --- Example: Expand network to include disability advocacy, women/LGTBIQ in engineering, or culturally diverse engineering firms	Connectivity: Internal and external stakeholders evaluate the evidence that the students have achieved the intended learning outcomes concerning personal, interpersonal, product, process, system, and service building skills. --- Tip/Example: Track student success and experience: CPD can help staff develop the skills to analyse and utilise student feedback to improve the inclusivity of courses. They can learn to assess how well students from diverse backgrounds are performing and adjust teaching strategies accordingly to ensure equity in learning outcomes.
Utilisation of relevant internal and external data for the embedding of EDI in the curriculum. (2/8)	Connectivity: Access to student data and reports from learning systems --- Tip/Example: Introduce department/faculty wide requirements for staff to demonstrate the analysis of internal data such as student demographics, academic performance, and engagement data to identify patterns and gaps in student experience related to EDI. This information could help tailor curriculum content and pedagogical approaches to better meet the diverse needs of students. For example, data may show that underrepresented groups are less engaged in certain areas, prompting staff to adapt teaching strategies or integrate more EDI-focused content.	Connectivity: Internal and external groups regularly review and revise program learning outcomes and/or program goals based on changes in stakeholder needs --- Tip: As part of CPD, staff can learn how to better incorporate feedback from a wide range of stakeholders—students, industry professionals, and community members—into curriculum design. This ensures that learning outcomes are reflective of a diverse range of perspectives and needs, which will ultimately enhance the student experience by preparing them for the global and diverse contexts in which they will operate as engineers. --- Example: Expand network to include disability advocacy, women/LGTBIQ in engineering, or culturally diverse engineering firms	Connectivity: When internal and external stakeholders review the integrated curriculum, they can make use of internal and external data to make adjustments as needed. --- Tip: The internal data may show patterns and gaps in student experience of the integrated curriculum, related to EDI. --- Example: Students with lower levels of interpersonal skills may be less able to make 'dual use of time'. There may be a need to offer additional support to those students, such as ensuring access to extracurricular clubs.
Incorporation of relevant research, scholarship and information for the development of the embedding of EDI in the curriculum. (3/8)	Connectivity : Connection here occurs across the entire set of standards. The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. The novel part here is about the use of research and scholarship as the basis for doing this embedded process. Certainly evidence based practice should be adopted for all aspects of teaching and learning wherever possible as this allows for better outcomes and implementation. This evidence base applies across each standard in how EDI can be integrated across the stages of CDIO, assessment, enhancement of competency, etc. as a means of maximising the success within each standard. Tips/Examples: Draw from scholarly research and frameworks such as: Critical Pedagogy (Paulo Freire), Universal Design for Learning, Trauma-informed teaching This guide (based on both the Advance HE and CDIO frameworks) Providing tip sheets and guidance for program staff, staff training, and incorporating recommendations into implementation plans, etc.		
Support for programme staff to trial and share outcomes of practices that embed EDI in the curriculum. (4/8)	Connectivity: Connection here occurs across the entire set of standards. The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. The novel part here is about supporting staff to trial and evaluate that embedding process. It is highly unlikely that a first iteration for any considerable change to a program will meet all the objectives to the desired standard. Instead, adopting an iterative approach to integration allows for some parts to be done as pilots, in lower stakes contexts, etc., for those moments to be learnt from and changes made in successive iterations until the work can be considered a success. Staff will need appropriate support to achieve this especially to ensure appropriate skill in running trials and evaluating their outcomes as well as having leadership support backing the process to inoculate staff operating in a complex space from bad actors who may seek to destabilise important work. Tip: Encourage staff to work collaboratively especially with others engaged in trial conduct. Examples: provide suitable training and leadership backup document resistance to change and how that can/has been effectively managed provide guidelines for trials and scaffold the kinds of evaluative data that can and should be collected connect these staff with learning design support.		
A member of the programme team is made responsible for oversight, promotion, facilitation and advice on EDI in the curriculum. (5/8)	Connectivity: The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. A member of the program team made responsible for oversight, promotion, facilitation and advice on EDI would benefit the review and development of all standards 1-8. Tip: The team member needs to have an effective and communicative relationship with all stakeholders and be able to back up their recommendations with evidence. Example: The team member responsible for EDI oversight may be an Educational Designer* that has qualifications and/or experience in implementation of EDI principles. They are then able to assist with elements of program design such as learning outcome development, active learning activity design, assessment design, staff training, etc. *In the context of Australian higher education, Educational Designers play a key role in facilitating this change. These professionals design, develop, and evaluate learning experiences, ensuring that curricula are inclusive, accessible, and aligned with both institutional goals and the diverse needs of students.		
Promotion of staff responsibility for EDI in the curriculum within recruitment and induction processes. (6/8)	Connectivity: Connection with the Advance HE EDI standards occurs across the entire CDIO process. This can occur through the development of selection criteria, recruitment processes, and recruitment standards that prioritise evidence of the integration of EDI within the curriculum. Induction procedures can leverage the CDIO processes to highlight the integration of EDI and inclusive theming across the whole curriculum. This is key within the educational leadership literature that demonstrates the importance of EDI practice to the organisation through organisational values, recognition, time allocation, promotion applications, etc. This encourages a greater variety of staff to participate and engage meaningfully. Tip/Example: Include contributions to EDI within teaching and learning as part of promotion applications for teaching staff.For example, consider asking "How has your teaching practice amplified the success and sense of belonging and connection of students across a broad set of identities and needs?".		
Recognition of staff contributions to EDI in the curriculum through reward, recognition and progression procedures. (7/8)	Connectivity: The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. Recognition of staff contributions to EDI can be evidenced across the entire CDIO process and all practice standards. Evidence may be sourced from staff co-creation of EDI-integrated learning outcomes, aligned assessments and integrated learning experiences. Reward, recognition and progression should prioritise evidence from the actualisation of EDI inclusive personal and interpersonal skills development, and product, process, system, and service building skill development across the cohort. This will help motivate and energise staff to remain engaged in the process Tip: Offer tangible rewards, such as celebration of individual/team efforts, increase importance in furthering career advancement and development opportunities, encourage staff to present on their work in valued spaces Example: The department organises an event for staff to present on their EDI contributions within the program, one individual/team receives an award selected by the Dean together with a people's choice award decided at the close of the event by participant votes.		
Monitoring and review of individual staff and overall programme team performance and impact in relation to EDI in the curriculum. (8/8)	Connectivity: Monitoring and review of individual staff and overall program team performance and impact in relation to EDI in the curriculum should cover all standards of the CDIO framework. Monitoring and review should be based on evidence of impact: student feedback, satisfaction, performance, and other outcomes, (for example employment, etc.) Tip: Use governance and feedforward approaches to program monitoring and review that encourages continuous improvement with respect to embedding EDI in the curriculum. Example: Instead of listing deficiencies in performance, utilise the CDIO framework (mapped to the Advance HE EDI framework) to focus on practical improvements that can be made.		

APPENDIX: PART 5B (OF 5) STAFF ENGAGEMENT
MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (4-6)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 4: Introduction to Engineering	Standard 5: Design-Implement Experiences	Standard 6: Engineering Learning Workspaces
Engagement in and utilisation of continuing professional development in the embedding of EDI in the curriculum to enhance practice. (1/8)	Connectivity: The introductory unit is regularly evaluated and revised, based on feedback from students, instructors, and other stakeholders. Rich qualitative feedback likely provided in unstructured free form flow. ---------- Tip/Example: Consider thematic analysis of information provided to organise into key components of pedagogical practices: content, educational technologies and tools, assessment, etc	Connectivity: The design-implement experiences are regularly evaluated and revised, based on feedback from students, instructors, and other stakeholders. ---------- Tip/Example: CPD can assist staff in designing engineering projects that require students to consider EDI factors. For example, creating products or systems that address challenges faced by underrepresented groups or considering diverse perspectives in product design.	Connectivity: Evaluation groups regularly review the impact and effectiveness of workspaces on learning and provide recommendations for improving them.. ---------- Tip/Example: Build staff fluency in UDL: multiple ways of representation, engagement and assessment
Utilisation of relevant internal and external data for the embedding of EDI in the curriculum. (2/8)	Connectivity: The introductory course is currently evaluated and revised based on feedback from students, instructors, and other stakeholders. Utilisation of data may also be useful for the embedding of EDI. ---------- Tip: A multi-pronged approach that combines feedback with data could reveal important information for the starting point of the introduction to engineering course. ---------- Example: Understanding the proportion of students who have completed Units 3 and 4 Maths Methods (VCE) to inform the study design.	Connectivity: Design-implement experiences allow students to make connections between the technical content and their professional/career interests. It could be helpful to have data on what career interests students have. ---------- Tip: Survey students to find out what their career interests are. This data may be helpful for designing D-I experiences that support EDI. ---------- Example: Students with fewer engineering role models or first in family university students may struggle to identify their career or professional interests. Knowing this could help support them in discovering their interests through DI experiences.	Connectivity: Data is valuable in ensuring the flexibility and effectiveness of workspace for student learning. ---------- Tip: Accessibility Support Services have data on the needs of students - make sure you know how to find it and make use of it, and ensure students do not need to follow up. ---------- Example: Accessibility Support Services data reveal students with hearing issues which reminds educators to use microphones in live sessions (validated closed captions for videos).
Incorporation of relevant research, scholarship and information for the development of the embedding of EDI in the curriculum. (3/8)	Connectivity : Connection here occurs across the entire set of standards. The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. The novel part here is about the use of research and scholarship as the basis for doing this embedded process. Certainly evidence based practice should be adopted for all aspects of teaching and learning wherever possible as this allows for better outcomes and implementation. This evidence base applies across each standard in how EDI can be integrated across the stages of CDIO, assessment, enhancement of competency, etc. as a means of maximising the success within each standard. Tips/Examples: Draw from scholarly research and frameworks such as: Critical Pedagogy (Paulo Freire), Universal Design for Learning, Trauma-informed teaching This guide (based on both the Advance HE and CDIO frameworks) Providing tip sheets and guidance for program staff, staff training, and incorporating recommendations into implementation plans, etc.		
Support for programme staff to trial and share outcomes of practices that embed EDI in the curriculum. (4/8)	Connectivity: Connection here occurs across the entire set of standards. The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. The novel part here is about supporting staff to trial and evaluate that embedding process. It is highly unlikely that a first iteration for any considerable change to a program will meet all the objectives to the desired standard. Instead, adopting an iterative approach to integration allows for some parts to be done as pilots, in lower stakes contexts, etc., for those moments to be learnt from and changes made in successive iterations until the work can be considered a success. Staff will need appropriate support to achieve this especially to ensure appropriate skill in running trials and evaluating their outcomes as well as having leadership support backing the process to inoculate staff operating in a complex space from bad actors who may seek to destabilise important work. Tip: Encourage staff to work collaboratively especially with others engaged in trial conduct. Examples: provide suitable training and leadership backup document resistance to change and how that can/has been effectively managed provide guidelines for trials and scaffold the kinds of evaluative data that can and should be collected connect these staff with learning design support.		
A member of the programme team is made responsible for oversight, promotion, facilitation and advice on EDI in the curriculum. (5/8)	Connectivity: The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. A member of the program team made responsible for oversight, promotion, facilitation and advice on EDI would benefit the review and development of all standards 1-8. Tip: The team member needs to have an effective and communicative relationship with all stakeholders and be able to back up their recommendations with evidence. Example: The team member responsible for EDI oversight may be an Educational Designer* that has qualifications and/or experience in implementation of EDI principles. They are then able to assist with elements of program design such as learning outcome development, active learning activity design, assessment design, staff training, etc. *In the context of Australian higher education, Educational Designers play a key role in facilitating this change. These professionals design, develop, and evaluate learning experiences, ensuring that curricula are inclusive, accessible, and aligned with both institutional goals and the diverse needs of students.		
Promotion of staff responsibility for EDI in the curriculum within recruitment and induction processes. (6/8)	Connectivity: Connection with the Advance HE EDI standards occurs across the entire CDIO process. This can occur through the development of selection criteria, recruitment processes, and recruitment standards that prioritise evidence of the integration of EDI within the curriculum. Induction procedures can leverage the CDIO processes to highlight the integration of EDI and inclusive theming across the whole curriculum. This is key within the educational leadership literature that demonstrates the importance of EDI practice to the organisation through organisational values, recognition, time allocation, promotion applications, etc. This encourages a greater variety of staff to participate and engage meaningfully. Tip/Example: Include contributions to EDI within teaching and learning as part of promotion applications for teaching staff.For example, consider asking "How has your teaching practice amplified the success and sense of belonging and connection of students across a broad set of identities and needs?".		
Recognition of staff contributions to EDI in the curriculum through reward, recognition and progression procedures. (7/8)	Connectivity: The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. Recognition of staff contributions to EDI can be evidenced across the entire CDIO process and all practice standards. Evidence may be sourced from staff co-creation of EDI-integrated learning outcomes, aligned assessments and integrated learning experiences. Reward, recognition and progression should prioritise evidence from the actualisation of EDI inclusive personal and interpersonal skills development, and product, process, system, and service building skill development across the cohort. This will help motivate and energise staff to remain engaged in the process Tip: Offer tangible rewards, such as celebration of individual/team efforts, increase importance in furthering career advancement and development opportunities, encourage staff to present on their work in valued spaces Example: The department organises an event for staff to present on their EDI contributions within the program, one individual/team receives an award selected by the Dean together with a people's choice award decided at the close of the event by participant votes.		
Monitoring and review of individual staff and overall programme team performance and impact in relation to EDI in the curriculum. (8/8)	Connectivity: Monitoring and review of individual staff and overall program team performance and impact in relation to EDI in the curriculum should cover all standards of the CDIO framework. Monitoring and review should be based on evidence of impact: student feedback, satisfaction, performance, and other outcomes, (for example employment, etc.) Tip: Use governance and feedforward approaches to program monitoring and review that encourages continuous improvement with respect to embedding EDI in the curriculum. Example: Instead of listing deficiencies in performance, utilise the CDIO framework (mapped to the Advance HE EDI framework) to focus on practical improvements that can be made.		

APPENDIX: PART 5C (OF 5) STAFF ENGAGEMENT
MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (7-9)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 7: Integrated Learning Experiences	Standard 8: Active Learning	Standard 9: Enhancement of Faculty Competence
Engagement in and utilisation of continuing professional development in the embedding of EDI in the curriculum to enhance practice. (1/8)	Connectivity: Units are regularly evaluated and revised regarding their integration of learning experiences and the impact of these experiences. --- Tip/Example: Build staff fluency in UDL: multiple ways of representation, engagement and assessment. Expand network to include disability advocacy, women/LGTBIQ in engineering, or culturally diverse engineering firms	Connectivity: Internal and/or external groups regularly review active learning activities on outcome-based learning across the curricula and make recommendations for continuous improvement. --- Tip/Example: Training on universal design for learning (UDL), differentiation, and culturally responsive teaching can enhance engagement for all students, ensuring active participation from a wide range of backgrounds.	Connectivity: Faculty competence in disciplinary knowledge and personal, interpersonal, product, process, system, and service building skills are regularly evaluated and enhanced where appropriate. --- Tip/Example: Faculty can enhance their own teaching competence by actively engaging in reflective practices related to EDI. This might include participating in peer review processes, conducting student surveys on inclusivity, and attending CPD on reflective practice. Through this, they can assess and refine their teaching methods, ensuring that they are actively supporting diverse student populations.
Utilisation of relevant internal and external data for the embedding of EDI in the curriculum. (2/8)	Connectivity: The effectiveness of pedagogical approaches for meeting the needs of diverse students may be revealed in relevant data. --- Tip: Include questions in student satisfaction surveys that tap into diverse student experience of pedagogical approaches. --- Example: Feedforward surveys ask if students feel they can bring their authentic selves to their learning, developing their personal and interpersonal skills while developing their disciplinary knowledge.	Connectivity: Active learning activities are a means of generating such data formatively (educators can listen in on student discussions) but also the design of those activities depends heavily on what students are ready for and what will be psychologically safe as well as effective for covering these concepts Tip: Collect plenty of informal data as the subject/course progresses to always ensure activity design is matched to student readiness Example: A formative task before class revealed students had not grasped the importance of accessible building design practices. As such an activity is designed for the coming class asking students to brainstorm collectively the least accessible design possible and then to flip this into what should be done instead	Connectivity: Embedding EDI concepts in curriculum can sometimes be challenging for educators especially in handling fears of pushback from a vocal minority of students. Educators need to be trained in not only respectfully embedding such content but also how to engage in respectful debate around them and sharing data on effective practices in the space is a crucial step in training up staff to perform this task. This covers both the knowledge of EDI concepts as well as the teaching practices of how to meaningfully embed them. Tip: Pair up teaching staff with those knowledgeable about the EDI space and practices in handling arising conflict, use the productive experiences from this as evidence and guidance for future work Example: The school/ discipline group runs a workshop for all teaching staff where they share findings from both productive and unproductive experiences embedding EDI concepts within the curriculum to allow all staff to learn and improve how they approach this within their own teaching
Incorporation of relevant research, scholarship and information for the development of the embedding of EDI in the curriculum. (3/8)	Connectivity : Connection here occurs across the entire set of standards. The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. The novel part here is about the use of research and scholarship as the basis for doing this embedded process. Certainly evidence based practice should be adopted for all aspects of teaching and learning wherever possible as this allows for better outcomes and implementation. This evidence base applies across each standard in how EDI can be integrated across the stages of CDIO, assessment, enhancement of competency, etc. as a means of maximising the success within each standard. Tips/Examples: Draw from scholarly research and frameworks such as: Critical Pedagogy (Paulo Freire), Universal Design for Learning, Trauma-informed teaching This guide (based on both the Advance HE and CDIO frameworks) Providing tip sheets and guidance for program staff, staff training, and incorporating recommendations into implementation plans, etc.		
Support for programme staff to trial and share outcomes of practices that embed EDI in the curriculum. (4/8)	Connectivity: Connection here occurs across the entire set of standards. The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. The novel part here is about supporting staff to trial and evaluate that embedding process. It is highly unlikely that a first iteration for any considerable change to a program will meet all the objectives to the desired standard. Instead, adopting an iterative approach to integration allows for some parts to be done as pilots, in lower stakes contexts, etc., for those moments to be learnt from and changes made in successive iterations until the work can be considered a success. Staff will need appropriate support to achieve this especially to ensure appropriate skill in running trials and evaluating their outcomes as well as having leadership support backing the process to inoculate staff operating in a complex space from bad actors who may seek to destabilise important work. Tip: Encourage staff to work collaboratively especially with others engaged in trial conduct. Examples: provide suitable training and leadership backup document resistance to change and how that can/has been effectively managed provide guidelines for trials and scaffold the kinds of evaluative data that can and should be collected connect these staff with learning design support.		
A member of the programme team is made responsible for oversight, promotion, facilitation and advice on EDI in the curriculum. (5/8)	Connectivity: The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. A member of the program team made responsible for oversight, promotion, facilitation and advice on EDI would benefit the review and development of all standards 1-8. Tip: The team member needs to have an effective and communicative relationship with all stakeholders and be able to back up their recommendations with evidence. Example: The team member responsible for EDI oversight may be an Educational Designer* that has qualifications and/or experience in implementation of EDI principles. They are then able to assist with elements of program design such as learning outcome development, active learning activity design, assessment design, staff training, etc. *In the context of Australian higher education, Educational Designers play a key role in facilitating this change. These professionals design, develop, and evaluate learning experiences, ensuring that curricula are inclusive, accessible, and aligned with both institutional goals and the diverse needs of students.		Connectivity: The member responsible for EDI ensures that faculty development training incorporates and demonstrates inclusive practices, thus making it more likely to be successful for all participant staff. Tip/Example: This staff member revises development training to ensure accessibility (e.g. multiple modes of engagement as per UDL) simultaneously increasing participant success and role modelling inclusive learning firsthand, so that individuals develop an awareness that helps them recognise when inclusivity is missing in other settings.
Promotion of staff responsibility for EDI in the curriculum within recruitment and induction processes. (6/8)	Connectivity: Connection with the Advance HE EDI standards occurs across the entire CDIO process. This can occur through the development of selection criteria, recruitment processes, and recruitment standards that prioritise evidence of the integration of EDI within the curriculum. Induction procedures can leverage the CDIO processes to highlight the integration of EDI and inclusive theming across the whole curriculum. This is key within the educational leadership literature that demonstrates the importance of EDI practice to the organisation through organisational values, recognition, time allocation, promotion applications, etc. This encourages a greater variety of staff to participate and engage meaningfully. Tip/Example: Include contributions to EDI within teaching and learning as part of promotion applications for teaching staff.For example, consider asking "How has your teaching practice amplified the success and sense of belonging and connection of students across a broad set of identities and needs?".		
Recognition of staff contributions to EDI in the curriculum through reward, recognition and progression procedures. (7/8)	Connectivity: The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. Recognition of staff contributions to EDI can be evidenced across the entire CDIO process and all practice standards. Evidence may be sourced from staff co-creation of EDI-integrated learning outcomes, aligned assessments and integrated learning experiences. Reward, recognition and progression should prioritise evidence from the actualisation of EDI inclusive personal and interpersonal skills development, and product, process, system, and service building skill development across the cohort. This will help motivate and energise staff to remain engaged in the process Tip: Offer tangible rewards, such as celebration of individual/team efforts, increase importance in furthering career advancement and development opportunities, encourage staff to present on their work in valued spaces Example: The department organises an event for staff to present on their EDI contributions within the program, one individual/team receives an award selected by the Dean together with a people's choice award decided at the close of the event by participant votes.		
Monitoring and review of individual staff and overall programme team performance and impact in relation to EDI in the curriculum. (8/8)	Connectivity: Monitoring and review of individual staff and overall program team performance and impact in relation to EDI in the curriculum should cover all standards of the CDIO framework. Monitoring and review should be based on evidence of impact: student feedback, satisfaction, performance, and other outcomes, (for example employment, etc.) Tip: Use governance and feedforward approaches to program monitoring and review that encourages continuous improvement with respect to embedding EDI in the curriculum. Example: Instead of listing deficiencies in performance, utilise the CDIO framework (mapped to the Advance HE EDI framework) to focus on practical improvements that can be made.		

APPENDIX: PART 5D (OF 5) STAFF ENGAGEMENT
MAPPING ADVANCE HE EDI FRAMEWORK (HANESWORTH, 2019) TO CDIO STANDARDS (10-12)

Columns from CDIO framework Rows from Advance HE EDI (Hanesworth, 2019)	Standard 10: Enhancement of Faculty Teaching Competence	Standard 11: Learning Assessment	Standard 12: Program Evaluation
Engagement in and utilisation of continuing professional development in the embedding of EDI in the curriculum to enhance practice. (1/8)	Connectivity: Guidance on incorporating diverse perspectives in technical subjects. Similar to below. Faculty teaching competence is regularly evaluated for evidence that the collective faculty has the teaching competence needed for effectively creating, delivering and improving courses in the curriculum and updated where appropriate. ---------- Tip/Example: Institutions should create formal evaluation mechanisms that assess faculty teaching competence in embedding EDI. This can include peer reviews, student evaluations, and self-assessment against EDI competencies, with results feeding into targeted professional development.	Connectivity: Internal and external groups regularly review the use of learning assessment methods and make recommendations for continuous improvement ---------- Tip/Example: EDI initiatives impact student learning outcomes. For instance, through CPD, faculty can learn how to analyse assessment data disaggregated by demographics to identify potential gaps or inequalities in student performance, ensuring that assessments are equitable. Staff guidance on the development of clear and transparent assessment rubrics that minimise bias and promote fairness. Regularly revising these criteria to ensure they are inclusive of diverse student experiences and identities can improve students' engagement with the assessment process.	Connectivity:. There is documented evidence that systematic and continuous improvement is based on continuous program evaluation results. ---------- Tip/Example: Communicate findings from program evaluations related to EDI efforts to all stakeholders, including students, faculty, and staff, and use the feedback to refine practices.
Utilisation of relevant internal and external data for the embedding of EDI in the curriculum. (2/8)	Connectivity: Embedding EDI concepts in curriculum can sometimes be challenging for educators especially in handling fears of pushback from a vocal minority of students. Educators need to be trained in not only respectfully embedding such content but also how to engage in respectful debate around them and sharing data on effective practices in the space is a crucial step in training up staff to perform this task. This covers both the knowledge of EDI concepts as well as the teaching practices of how to meaningfully embed them. Tip: Pair up teaching staff with those knowledgeable about the EDI space and practices in handling arising conflict, use the productive experiences from this as evidence and guidance for future work Example: The school/ discipline group runs a workshop for all teaching staff where they share findings from both productive and unproductive experiences embedding EDI concepts within the curriculum to allow all staff to learn and improve how they approach this within their own teaching	Connectivity: Assessment is a tool to generate data about students' knowledge, skills and attitudes. Ergo assessment would generate some of this data. Drawing from earlier data sources (including earlier assessments) is also necessary in the design of assessed tasks to ensure they are pitched based on student readiness and this applies for EDI concepts within assessment as well Tip: Perform diagnostic assessments and collect data from class activities around EDI concept prior to assessment thereof to maximise student success and identify necessary supports Example: Software engineering students are exposed to concepts around Indigenous data sovereignty, surveying is done prior to it arising in a coming assessment to ensure students are prepared to integrate those concepts and ensure ethical data collection and retention for the applications they build	Connectivity:In evaluating the program it is necessary to review the effectiveness of activities, curriculum/content/etc., EDI concepts within the curriculum thus also need to be evaluated and data is necessary in order to do this effectively and support ongoing improvement Tip: Often EDI concepts are about more than just content knowledge, they are about attitude change. Aim to collect data about students changing attitudes including asking student representatives Example: Pre and post surveys run with students fitting around key EDI elements in the curriculum to see how if at all their perspectives have changed by exposure to those ideas
Incorporation of relevant research, scholarship and information for the development of the embedding of EDI in the curriculum. (3/8)	Connectivity : Connection here occurs across the entire set of standards. The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. The novel part here is about the use of research and scholarship as the basis for doing this embedded process. Certainly evidence based practice should be adopted for all aspects of teaching and learning wherever possible as this allows for better outcomes and implementation. This evidence base applies across each standard in how EDI can be integrated across the stages of CDIO, assessment, enhancement of competency, etc. as a means of maximising the success within each standard. Tips/Examples: Draw from scholarly research and frameworks such as: Critical Pedagogy (Paulo Freire), Universal Design for Learning, Trauma-informed teaching This guide (based on both the Advance HE and CDIO frameworks) Providing tip sheets and guidance for program staff, staff training, and incorporating recommendations into implementation plans, etc.		
Support for programme staff to trial and share outcomes of practices that embed EDI in the curriculum. (4/8)	Connectivity: Connection here occurs across the entire set of standards. The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. The novel part here is about supporting staff to trial and evaluate that embedding process. It is highly unlikely that a first iteration for any considerable change to a program will meet all the objectives to the desired standard. Instead, adopting an iterative approach to integration allows for some parts to be done as pilots, in lower stakes contexts, etc., for those moments to be learnt from and changes made in successive iterations until the work can be considered a success. Staff will need appropriate support to achieve this especially to ensure appropriate skill in running trials and evaluating their outcomes as well as having leadership support backing the process to inoculate staff operating in a complex space from bad actors who may seek to destabilise important work. Tip: Encourage staff to work collaboratively especially with others engaged in trial conduct. Examples: provide suitable training and leadership backup document resistance to change and how that can/has been effectively managed provide guidelines for trials and scaffold the kinds of evaluative data that can and should be collected connect these staff with learning design support.		
A member of the programme team is made responsible for oversight, promotion, facilitation and advice on EDI in the curriculum. (5/8)	Connectivity: Actions in this standard include ensuring teaching competence is included in hiring and performance reviews. By ensuring EDI is included in these processes, the potential for bias is minimised Tip: Include this member in recruitment and promotion of faculty members. Example: They might help with everything from reviewing position descriptions to questions asked in interviews, and reviewing promotion applications.	Connectivity: Internal and external groups regularly review the use of learning assessment methods and make recommendations for continuous improvement---------- Tip: include EDI champions in the review of learning assessment methods. ---------- Example: Invite external EDI champions as well as diverse student groups to participate in reviews of learning assessment methods	Connectivity: A dedicated staff member in an oversight position is essential to program evaluation being meaningful with respect to EDI. Tip/ Example: Such a staff member may be involved in reviewing evaluation data with a focus on equity outcomes. Collaborating on improvement plans to address gaps identified, ensuring EDI is not treated as an "add-on" but a core dimension of educational quality. All of which increase the reliability of the evaluation process and how informative it is
Promotion of staff responsibility for EDI in the curriculum within recruitment and induction processes. (6/8)	Connectivity: Connection with the Advance HE EDI standards occurs across the entire CDIO process. This can occur through the development of selection criteria, recruitment processes, and recruitment standards that prioritise evidence of the integration of EDI within the curriculum. Induction procedures can leverage the CDIO processes to highlight the integration of EDI and inclusive theming across the whole curriculum. This is key within the educational leadership literature that demonstrates the importance of EDI practice to the organisation through organisational values, recognition, time allocation, promotion applications, etc. This encourages a greater variety of staff to participate and engage meaningfully. Tip/Example: Include contributions to EDI within teaching and learning as part of promotion applications for teaching staff.For example, consider asking "How has your teaching practice amplified the success and sense of belonging and connection of students across a broad set of identities and needs?".		
Recognition of staff contributions to EDI in the curriculum through reward, recognition and progression procedures. (7/8)	Connectivity: The mapping of Advance HE EDI Curriculum Design standards verified the mapping of these concepts themselves into the curriculum. Recognition of staff contributions to EDI can be evidenced across the entire CDIO process and all practice standards. Evidence may be sourced from staff co-creation of EDI-integrated learning outcomes, aligned assessments and integrated learning experiences. Reward, recognition and progression should prioritise evidence from the actualisation of EDI inclusive personal and interpersonal skills development, and product, process, system, and service building skill development across the cohort. This will help motivate and energise staff to remain engaged in the process Tip: Offer tangible rewards, such as celebration of individual/team efforts, increase importance in furthering career advancement and development opportunities, encourage staff to present on their work in valued spaces Example: The department organises an event for staff to present on their EDI contributions within the program, one individual/team receives an award selected by the Dean together with a people's choice award decided at the close of the event by participant votes.		
Monitoring and review of individual staff and overall programme team performance and impact in relation to EDI in the curriculum. (8/8)	Connectivity: Monitoring and review of individual staff and overall program team performance and impact in relation to EDI in the curriculum should cover all standards of the CDIO framework. Monitoring and review should be based on evidence of impact: student feedback, satisfaction, performance, and other outcomes, (for example employment, etc.) Tip: Use governance and feedforward approaches to program monitoring and review that encourages continuous improvement with respect to embedding EDI in the curriculum. Example: Instead of listing deficiencies in performance, utilise the CDIO framework (mapped to the Advance HE EDI framework) to focus on practical improvements that can be made.		

EXAMPLES OF ENABLERS FOR CURRICULUM AGILITY

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ABSTRACT

Within six institutions, Chalmer's University of Technology, Delft University of Technology, Eindhoven University of Technology, NTNU, Queen's University Belfast, and Umeå University, activities of self-mapping Curriculum Agility have taken place, facilitated by the co-creators of this work. In this paper, they reflect on enablers of Curriculum Agility that they identified during the self-mapping process at their respective institutions. By putting a spotlight on enablers, ways to overcome obstacles are exemplified, when the ambition is to proactively futureproof an engineering curriculum. These enablers help in four curriculum innovation areas, which each have their own challenges: (1) Continuously adjusting learning content in courses, creating a need for a teaching and learning system with more dynamic learning goals and on-the-go, reciprocal expertise development. (2) Implementing or refining flexible education pedagogy and didactics to tailor to and being inclusive of the diverse student populations entering university. (3) Working with a responsive organisation and a continuously-change-facilitating management, where engagement and ownership of educational innovation is shared, and innovation space is constructively created where desired and needed. (4) Continuously developing all academic staff involved in engineering education innovation, for informed decision-making and shared understanding of the pedagogic and (inter- and trans-) disciplinary innovations needed to keep the engineering programme relevant and of high quality. This paper highlights positive examples of Curriculum Agility, and how its characteristics and principles can be implemented in a variety of university contexts with different organisational structures.

KEYWORDS

Curriculum Agility, Transformative Curriculum Change, Futureproof Engineering Education, Change Management, Standards: 1-12, Optional standards: 1-4

INTRODUCTION

The concept of Curriculum Agility (Brink et al., 2024a) emerged from the need for educational systems to be more responsive to rapid changes in society and technology, and widening student population characteristics. The student population has become more diverse due to successful inclusion efforts and lifelong learning developments, creating a need for curricula that can be tailored and adapted promptly to meet a diverse range of individual needs. Technology is present to enable this. Online resources, digital classrooms, and AI-driven adaptive learning systems encourage a shift towards dynamic, customizable learning experiences. With the rise of technology and globalization, the skills and knowledge that are relevant for students to learn quickly become outdated and are in need of continuous adjustment (Kamp, 2016). Employers seek individuals who can adapt, think critically, and innovate (Malmqvist et al., 2022), and society needs graduates who are able to work on global sustainability challenges (Hanstedt, 2023), which are both complex and uncertain. Existing curricula need to be adaptable to prepare students for this increasingly unpredictable world, resulting in numerous concepts of 21st century skills for digital literacy, sustainability, and social transformation (Kopnina, 2020) (Hoggan, 2016). That the changes deemed necessary are ever developing is evident in the sub-themes of this conference, which includes ethics, emotions, and transdisciplinary approaches.

In an era of constant demands for updates to engineering curricula, guidance is sought to make curricula more agile. This concept of Curriculum Agility has been developed between 2018 and 2023 in a series of focus group sessions with engineering education practitioners and experts. Throughout these co-creational and iterative sessions, Curriculum Agility was defined an on-going innovative framework for establishing a responsively organised education, with dynamic learning contents and flexible pedagogy and didactics, and with all involved staff continuously developing competency to deal with the necessary transitions. Figure 1 highlights these four core characteristics of Curriculum Agility and ten principles that directly influence such responsive curriculum change processes (Brink et al., 2024a).

When course content is more dynamic it can be responsive to relevant developments in a timely manner. Pedagogy and didactics that are flexible and tailor-made help the learning experiences of an ever more varying student body. When the organisation and management are co-creators in curriculum development, their informed involvement in desirable changes grows with their responsiveness. In that sense, staff development is pivotal in educational innovation not only for teaching staff, but for all who are involved in the design, decision making, and operation of the engineering curricula.

The ten principles of Curriculum Agility emphasise dialogue in a proactive approach for all stakeholders involved in curriculum development, change, and innovation. Note that they are not one dimensional and do not have a single solution or absolute measure defining them. They accommodate the local values and context, making Curriculum Agility more inclusive and relevant in a worldwide engineering education setting. They cover education, organisation and overarching themes. When discussing curriculum change on programme level in both local institutional contexts and broader academic cultures, numerous barriers were mentioned. These barriers made it challenging to increase flexibility and responsiveness, even when the need was recognized within the participating higher education institutions. The barriers were the grounds for the principles.

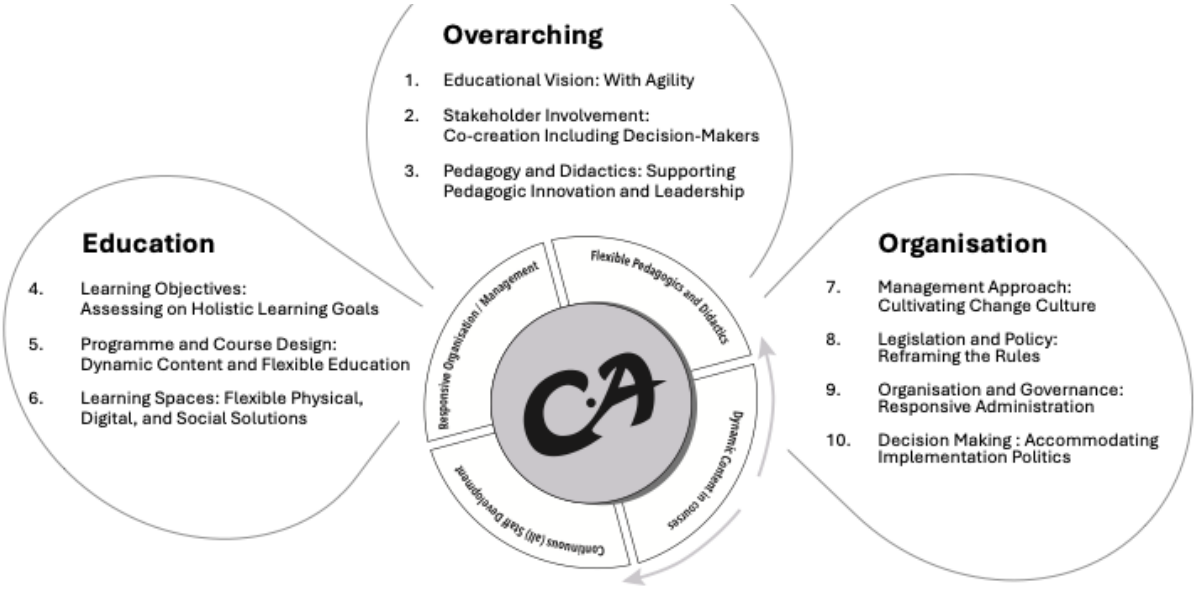


Figure 1: Curriculum Agility and its principles (Brink et. al., 2024a)

Besides the barriers, good examples were also part of identifying the principles. Higher education institutions (HEIs) are organized and run differently everywhere, and local, regional, and national differences make some principles easier or more established than others in certain contexts. While mapping their Curriculum Agility, six European universities gained detailed insights into where their institution stood on these relative, pluriverse, qualitative scales of the principles. We discuss the enablers in this paper for inspiration and as a counterweight to all the barriers - sometimes seen as obstacles - that we, as critical-thinking academics, are prone to focus on.

METHOD

For this study, illustrative examples of enablers for Curriculum Agility were collected. Six universities from Sweden, The Netherlands, UK, and Norway, participated in a pilot of mapping Curriculum Agility at their own institutions: Umeå University (UmU), Chalmers University of Technology (Chalmers), Delft University of Technology (TU Delft), Eindhoven University of Technology (TU/e), Queens University Belfast (QUB), and NTNU University of Technology (NTNU) at different institutional levels (Brink et al., 2024b). The mapping process comprised of five steps: informing, probing, envisioning, strategizing and prioritizing. A protocol with information, worksheets, and tips on each step was offered to the mapping facilitators, co-authors of this paper. The facilitators had different positions within their organisation: head of school, head of education, director of educational services, academic developer, head of programme, and strategic consultant. Based on their first-hand experiences during the mapping, each facilitator reflected on what enablers had been identified by the participants.

Data analysis

Each facilitator wrote a narrative describing their identified strengths and enablers. The facilitators' observations were discussed and categorized into three categories during four online focus group meetings with the other facilitators, as can be seen in the result section.

RESULTS

The results are presented in three parts. First, we describe enablers categorized under the characteristics Flexible Pedagogy and Didactics and Dynamic Contents of Courses, next the responsive organisation, and lastly the continuous staff development.

Flexible Pedagogy and Didactics & Dynamic Contents of Courses

Several of the facilitators observed enablers that made their HEIs advance towards flexible pedagogy and didactics, and facilitating courses to offer dynamic contents to their students.

The TU/e Vision on Education guides the university's future direction, focusing on (1) preparing engineers to tackle major societal, technical, and scientific challenges and (2) providing high-quality, adaptable education for a rapidly changing world. This vision enhances TU/e's resilience to global changes, shaping it into a learning organization that fosters diverse T- and π-shaped engineers with knowledge in different disciplines and interdisciplinary expertise. Developed collaboratively with staff and students, the vision embraces continuous learning, reflection, and development. University-wide initiatives, curriculum innovations, and bottom-up projects explore and implement educational advancements tailored to TU/e, such as Challenge-Based Learning (CBL), digitalization, and flexibility. Key elements include interactive, small-scale campus learning enriched by digital tools, strong industry and research collaborations, and team-teaching approaches. Research and education are deeply connected with sustainability (Sustainable Development Goals), playing a central role.

A vision that embeds agility enables curriculum flexibility, and TU/e exemplifies how such a vision drives meaningful change. Diverse stakeholders—teachers, policymakers, and educational experts—have contributed, with the broader university community engaged through dialogue sessions. Several aspects of the vision have been translated into university-wide programs that support faculties and educators in creating more flexible, dynamic study programs.

At NTNU, the project Technology Education of the Future was established in August 2019. A framework for NTNU's educational portfolio in technology was developed to ensure that NTNU's portfolio of technology and engineering programs is well aligned with technology development, societal challenges, and industry needs for a future beyond 2025. In the final report (Øien and Bodsberg, 2022) Curriculum Agility was recognised as a necessary feature for the educational portfolio and that its principles were fully compatible with the recommendations put forward in the project Technology Education of the Future. The only aspect of the three principles not explicitly addressed in the university policy documents were that agility is not explicitly incorporated in the vision. Work on the future strategy is presently on-going, and agility is likely to be addressed in the work.

An important enabler for flexible and dynamic education at Chalmers is their Tracks initiative. Tracks courses are not tied to any specific department, school, or programme but are open to all students, ranging from second-year BSc students to those at the MSc and PhD levels, as well as for professionals. Courses are proposed through open calls, encouraging contributions from faculty and external collaborators. To qualify, courses must address pressing societal challenges and/or cutting-edge research, attract students from multiple programs, feature diverse teaching teams, integrate interdisciplinary projects where students with varied backgrounds collaborate, and actively involve external stakeholders.

Tracks courses bring together students from various programs and levels, as well as professionals, fostering a collaborative environment where they learn both together and from

one another. To maintain relevance, each approved course is offered only three times. Through Tracks, dynamic learning contents are realised by swiftly integrating emerging technologies, materials, and concepts into its education, responding effectively to the needs of industry and society. New courses can be developed and implemented in as little as three months, complementing the more structured, program-based educational framework.

Chalmers Fuse, an innovation lab with a flexible and dynamic learning environment focused on design, build, test, and experiential learning, is an important part of the Tracks initiative. It enables cross-disciplinary collaboration by bringing together participants from diverse programs, fields, and sectors to learn, innovate, conduct research, and test new ideas. While it primarily hosts Tracks courses, Chalmers Fuse also supports other educational activities, projects, start-ups, and events in collaboration with industry and society.

Aligning with the Bologna model (BSc + MSc), an enabler for agility is Chalmers' 3+2 programme structure. Unlike traditional five-year engineering programmes in Sweden, this format allows students to choose from a variety of master's programmes after the third year. It also enables faster implementation of curricular changes, as major updates can be delivered much faster, compared to a five-year programme cycle.

Additionally, Chalmers is revising its master's-level offer, with existing programmes being replaced with broader, more interdisciplinary platforms. These new master's programmes begin with a common core, followed by specialized and replaceable tracks that provide depth and professional skills. This modular approach allows for quicker creation or discontinuation of specializations, enhancing responsiveness to industry, research, and individual needs. The curriculum development is collaborative, involving faculty, students, and external stakeholders, and often spans multiple departments, fostering interdisciplinary learning, research, and innovation.

Many TU Delft degree programs, 3-year bachelor's and 2-year master's, have a fixed core curriculum with separate tracks that students can choose. The learning objectives and learning content of courses are relatively fixed. The dynamics of course content vary considerably between faculties and degree programs. The most recent degree programs and the forthcoming new degree programs have much more dynamic content and pedagogies than Delft's traditional degree programs. Larger curriculum renewals (1x per 5-10 years) are the moments to fundamentally reconsider programme and course content. This process is usually led by the degree programme leader and/or the Faculty's Director of Education.

These are opportunities that could enable a more agile curriculum at TU Delft. Individual degree programme leaders align the pedagogical philosophy and approach of their programme with their Faculty's Director of Education. Degree programme leaders and their Faculty Director of Education talk to their Faculty Board of Studies (both student and teacher representatives), their Board of Examiners (teachers), and their Faculty Student Council about pedagogical policies and practices. Academic freedom is important to teachers, course coordinators, and degree programme leaders, giving them agency to decide their didactic approach in their class, course, and/or degree programme within the context and conditions of the education vision of the School/Faculty, degree program, or course. This means that individual teachers and course coordinators in Delft are given ample room and support to develop their pedagogy and didactics within courses, usually in close collaboration with their course teaching team of lecturers, professors, and teaching assistants. Educational advisors, blended learning developers, and the Media Centre, are available to support the execution, development, or innovation of teaching practices. Course coordinators align their learning and

teaching activities and assessment strategies with the degree programme leader, to keep each other accountable.

UmU offers two compulsory faculty-wide courses in all engineering programmes: the Design-Build-Test Project and Sustainability for Engineers. Students of different engineering disciplines meet each other and work over the borders of their own discipline. In a relatively direct way these courses can be tweaked, adjusted, and offer dynamic learning content by changing projects and clients. Programmes have several designated moments where students are free to choose electives, giving them flexibility to specialize as desired.

Responsive Organisation and Management

As the participating institutions have different organisational structures, resulting in different perspectives on responsiveness, the self-mapping processes showed a variety of enablers.

At QUB, a 2030 strategy was developed to enhance education and research, with input from staff, students, and external stakeholders. Part of the education and skills strand of this strategy is centred on a course management framework, which included a project to improve the approval processes for curriculum and course changes. This project sought to implement a risk-based, enhancement-focused approach to these approval processes that ensured agility while complying with Competition and Markets Authority (CMA) guidance. The project concentrated on staff engagement and sectoral benchmarking to identify barriers and enablers to change in the existing processes. This included reviewing definitions and classifications of changes, change authorities and responsibilities, communication processes, operational procedures and documentation, and CMA guidance. Engagement workshops were held with representatives from all schools, faculties, and relevant directorates within the university, as well as local educational partners. Their aim was to fully understand these barriers and enablers to curriculum and course approval and adjustment, and develop more agile, compliant approval processes. This subsequently led to revised processes, which were endorsed by the university. The activities included mapping current curriculum and course approval processes, reviewing CMA compliance, and current processes and forms, establishing criteria for major changes and delegation to committees, and identifying ways to increase agility and addressing constraints.

On completion, QUB's project to approve curriculum and course changes was reviewed and mapped against the ten principles of Curriculum Agility. It has promoted a more dynamic and responsive approach to curriculum change, thus ensuring the university can adapt to societal and technological shifts. Its engagement with staff, students, and external stakeholders has established new processes to ensure that future curriculum transformation can meet the evolving needs of all parties involved. The project emphasis was on flexible and enhancement-focused curriculum approval processes that allow for the integration of holistic and adaptable learning outcomes. By definition, the project has fostered a culture of change and innovation through proactive engagement and improvement of existing curriculum development processes. By adhering to CMA guidance whilst pursuing greater agility, the project has demonstrated how to navigate and innovate within existing regulatory frameworks. The inclusion of representatives from all university sectors has ensured that the administrative structure supports and maintains curriculum changes effectively. Thus, the project has succeeded in streamlining curriculum approval processes and making them more transparent agile and efficient.

Looking into aspects that can be seen as enablers for establishing Curriculum Agility, at NTNU there are several factors that can be argued to be useful. First among these is the work done

in the project Technology Education of the Future. The reports from the project recommend the establishment of a vision for the STEM-educations at NTNU and of holistic competence goals for the study programmes and also provides a large number of concrete recommendations to be implemented at different levels of the organization, with clear recommendations on who should be the responsible actors. Second, the project process has been a benchmark study in co-creation where stakeholders, both external and internal, have actively collaborated in the project. The result is that the project recommendations are broadly anchored among staff and departments at NTNU, which provides a template for going forward. In other words, faculty staff from deans, through pro-deans for education, heads of study programmes, department heads, and teaching staff are not only reasonably well-informed about the project but also about the desired development work.

At TU/e, innovations, especially at the curriculum level, are part of a co-creation process involving programme directors, bachelor and master deans, and other stakeholders. Following the establishment of the education vision, initiatives are underway to implement various elements of the vision, such as Challenge-Based Learning and Personal & Professional Development, into the engineering programs' curricula. The implementation of these innovations occurs at multiple levels. On policy development, by creating directives and guidelines that cover regulations on bachelor curriculum and innovative educational elements, to integrate, for instance, CBL in the curricula. The process of developing the directives is a co-creation process in which Program Directors and dean Bachelor College in the Bachelor Curriculum Committee agree on the guidelines. These guidelines are also discussed with co-determination and consultation university bodies before being definitively approved. Each department has established a curriculum committee. The Program Directors also discuss the bachelor guidelines with their own Curriculum Committees in their own faculties. These committees consist of programme directors, teachers, teacher support staff, and, to some extent, students. They collaborate on integrating innovations and redesigning the curriculum. Education staff (e.g. staff responsible for the support and implementation of education) are also involved and consulted.

At Chalmers, programme advisory boards are engaged in ongoing processes of programme and course development. These advisory boards consist of representatives from industry and society, students and teachers, and thereby providing both indirect and direct stakeholder input on how programmes should develop. Besides offering flexibility to students, the 3+2 bachelor-masters model at Chalmers results in increased organisational flexibility and shorter response times, as changes can be made on both levels independently. Efforts are ongoing to make the master’s level more flexible organisationally, with minors and specializations that can be added or changed without having to start new programmes.

TU Delft has many hierarchical levels and sub-units that are responsible for leading, organizing, and managing education, and the decision-making and governance processes vary per Faculty. On the one hand, this makes the decision-making process complicated, less transparent, and relatively slow, therefore less agile. On the other hand, many stakeholders already play a role in the curriculum development. Directors of Education, Degree programme leaders and their course coordinators, Education managers such as the director (central) and heads (local) of ESA, and the Boards (Board of Studies, Board of Examiners, Student Council) all meet separately and together regularly. In addition, responsibility is given to students and student bodies in decision-making, such as in curriculum renewal processes. Study associations and the formal Student Councils (Central and Faculty level) are well-organised and are seen as pivotal partners in developing, organizing, managing, or advising on the education.

Continuous Development of (All) Academic Staff

At UmU, the development of innovative pedagogic competencies among its academic staff is supported through a variety of staff development courses and workshops, both for new and experienced academic staff. In these, participants from different disciplines and teaching cultures meet and get inspired by each other, from engineering to humanities, to medical and social sciences. These efforts are driven by UmU's Centre for Educational Development (UPL), as well as by specialized activities within its faculties. In a practice as you preach way, UPL's courses and workshops are designed to be flexible and personalized and always varied in learning activities to be inclusive to the different teaching traditions and values in the different departments. Pedagogic leadership and scholarship of teaching are fostered, aimed at student- and learning-centred approaches. Pedagogical innovation is valued, and next to academic developers' support in curriculum innovation processes, central funding is available for innovative initiatives and explorations by academic staff on a yearly basis. In addition, teaching excellence is rewarded through promotions and a meriting system with financial benefits. Management signals the importance of such pedagogic quality development by awarding the merited and distinguished teachers alongside those receiving research awards.

The TU/e vision on education embraces the concept of a learning organization by emphasizing the support of academics and teachers in their teaching roles and providing opportunities to develop their knowledge and skills, contributing to the Continuous Professional Development (CPD) of teachers. Pedagogic innovation goes hand-in-hand with supporting teaching staff and their professional growth. To facilitate the professional development of TU/e teaching staff beyond the compulsory University Teaching Qualification (UTQ), which covers the basics of educational competencies (designing, teaching, assessment, organisation of education, and professionalization), TU/e offers CPD pathways. These pathways are flexible and optional for those seeking further professionalization, career ambitions and/or in need to upgrade their educational knowledge and skills regarding new challenges in pedagogy and/or tools, i.e. Challenge-based learning, AI, etc.

The TU/e has stated a Reward & Recognition Policy to acknowledge education career development at the same level as research output. In addition, the TU/e Academy for Learning and Teaching (ALT) serves as a platform for dissemination of innovations and provides support for teaching staff to carry out innovations and equip them with the necessary skills. For senior academic staff, such as Program Directors or teachers with curriculum development responsibilities, an Education Leadership Program is available. This programme equips senior staff with substantial knowledge of educational theories and leadership skills, enabling them to lead redesigning of the curriculum, educational innovations and reforms.

TU Delft's central department of Teaching and Learning Services is responsible for Delft's institutional staff development programme, but the Teaching Academy (TA) is the community that runs the physical hub for all university teachers to meet, share, inspire, exchange, and learn from each other. The TA hosts the institutional Education Fellowship programme and the yearly TU Delft Education Day, where good teaching practices, educational innovations, and education research are presented and discussed. Other subunits and programs such as the Extension School (online education), the 4TU Centre for Engineering Education, the Delft-Rotterdam Convergence program, Delft's AI program, and many more also offer teaching staff opportunities for staff development. In the last years, Delft hired tens of new Academic Career Trackers (Assistant Professor level) with an emphasis on teaching and learning in their track,

in line with the Dutch university policies on diversifying academic career paths. This brings new momentum to advance TUD's teaching culture.

One of NTNU's outcomes of the project Technology Education of the Future was the further development and support of a centre for Science & Engineering Education Development (SEED). From 2023 onwards SEED has run seminars for faculty education committees, heads of study programmes, and participated in programme development work. The work has arguably had a considerable and immediate impact in establishing a change mindset among the management. The centre has chosen as a supporting strategy to negotiate invites to already existing meeting arenas where middle management staff is informed about the details of implementing the recommendations from the project Technology Education of the Future. At the meetings analytical tools to use in their development work have been presented and tested. The meeting places have been regular meetings, such as faculty educational committees, educational days, and department meetings that already are scheduled. The fact that the meetings are already schedules means that they are not seen as an extra burden in a busy calendar, and the outcomes of the meetings have been very well received. Another aspect worth mentioning as an enabling factor is the programme for recognition of pedagogical merits. Teachers that can show that they meet a set of four criteria for high quality teaching are rewarded with a raise in salary and a lump sum to be used for further education development at their discretion.

DISCUSSION AND CONCLUSIONS

This paper provides insights into enablers for Curriculum Agility as defined by Brink et al. (2024a) in Figure 1. The study across six institutions demonstrated how self-mapping Curriculum Agility can identify enablers on the ten principles for Curriculum Agility, which were formulated through a five-year, co-creational process in engineering education, involving practitioners and experts from worldwide CDIO member-institutions. The enablers shared in this paper illustrate practical examples for the higher engineering education community. In the six institutions, enablers were found in professional development and teaching merits reward structures for at least academic teaching staff, but in some cases also already including all academic staff. Enablers were also identified in stakeholder involvement, co-creation of university or department-wide visions and educational development initiatives, and decision-making processes on curriculum innovations. To ensure that agility permeates all levels of the organization, it is essential to integrate these principles into institutional strategies, fostering a culture of innovation and adaptability. The self-mappings also demonstrated that Curriculum Agility is an ongoing journey, inherently requiring continuous effort and adaptation to benefit students, industry, and society by creating more responsive and inclusive educational environments. This continuous process can be facilitated by using the co-creative, multiple-stakeholder CA self-mapping protocol (see also Brink et al, 2024b).

TU/e's emphasis on continuous learning and innovation fosters a co-creative approach to curriculum design, while its professionalization and recognition systems cultivate a culture of change. This implementation of university-wide initiatives, innovative curricula, and bottom-up projects promoted an environment where evidence-based adjustments are made iteratively.

Similarly, NTNU's approach of strongly recommending holistic learning outcomes on programme level and QUB's curriculum management framework showcase robust strategies to enhance agility. These efforts embraced a culture of change and innovation, ensured administrative support for curriculum development, and facilitated sustainable teaching and learning practices. It has helped stimulate a model for an agile and responsive education.

A fundamental aspect of Chalmers' Tracks initiative is the principle of Stakeholder Involvement. Tracks are designed to provide students with opportunities to develop interdisciplinary and cross-disciplinary competencies while pursuing individualized study paths as elective parts of their education. The initiative also aims to shorten the lead times for adapting education to emerging technologies, new materials, and innovative concepts. By combining flexibility, innovation, and collaboration, it has created a transformative educational experience that aligns with the demands of a rapidly changing world.

TU Delft's flexible project-based education exemplifies efforts to incorporate dynamic content and interdisciplinary learning, though challenges remain in ensuring wider student participation and streamlined decision-making processes due to many who are involved. The same goes for UmU's joint Design-Build-Test and sustainability courses that are given in all engineering programmes and where students of the different disciplines meet each other. At TU Delft, although the more traditional engineering degree programs are less dynamic and flexible in programme and course content, there is a lot of flexibility in didactics and pedagogies and within project education, the elective space, and in extracurricular activities. Most of the newer, inter- and transdisciplinary programmes are designed to be more agile.

UmU's meriting system that actively supports scholarship of teaching and learning underlines the importance of not only engaging academic teachers but also managers in staff development initiatives. UPL offers not only pedagogic courses, but also curriculum innovation consultancy directed at involving all programme stakeholders. TU Delft's support staff and pedagogical experts such as E-learning developers and educational advisors stimulate and facilitate the development and implementation of innovative, flexible pedagogies including assessment strategies. TU/e also acknowledges that teacher professionalization and a recognition and reward system that values education and innovation is crucial.

The enablers discussed are not exhaustive, or indicative for the overall curriculum flexibility of each institution. They should rather be seen as examples of how the characteristics and principles of Curriculum Agility can manifest themselves in different institutional structures and educational contexts. The discussed enablers do underscore that achieving greater Curriculum Agility is an enduring, multi-stake process. While they exemplify effective strategies and structural strengths, they also revealed areas to the facilitators where further work is needed to ensure agility at all levels from the perspective within their organisations. It could also be concluded that the differences in enablers were to be seen from within the local contexts rather than be inter-comparable between the participating institutions. But hearing each other's enablers did inspire.

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DESIGNING A TOOL TO MEASURE INNOVATION COMPETENCE SELF-PERCEPTION IN ENGINEERING STUDENTS

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ABSTRACT

This paper presents the development and validation of a survey as a tool to measure innovation self-perception competence in early-year engineering students at the Faculty of Physical and Mathematical Sciences, University of Chile. Based on the INCODE Innovation Competencies Barometer, the self-assessment tool was adapted to the local context, validated, and refined through a pre-pilot and pilot study before the subsequent deployment. This validation included psychometric tests and factor analysis. The results show that the tool is reliable and effective in assessing key dimensions of innovation self-perception, such as creativity, critical thinking, initiative, teamwork, and networking. The information obtained helps identify areas for improvement in educational programs, ensuring that courses align with formative objectives and contribute to developing engineers prepared to address technological and social challenges with an innovative mindset. This tool provides a robust basis for continuous improvement in teaching innovation, aligning academic training with labour market demands and global challenges for engineering graduates.

KEYWORDS

self-assessment, competence measurement, educational evaluation, innovation, CDIO Standards 2, 5, 7.

INTRODUCTION

Engineering education increasingly recognises the critical role of strengthening innovation competence in preparing students to tackle complex global challenges. According to The Oslo Manual (OECD, 2018), innovation significantly improves products, processes, or services. This is well integrated into some LATAM Engineering and Sciences schools, such as the Faculty of Physical and Mathematical Sciences (FCFM) of the University of Chile, the oldest engineering school in Chile.

Innovation competence fosters the ability to identify opportunities, generate novel ideas, and implement effective solutions (OECD, 2018) in students; however, the measurement of competence progression through time has not been achieved yet. Frameworks such as the Innovation Competence Barometer (ICB) identify five essential dimensions for fostering innovation: creativity, critical thinking, initiative, teamwork, and networking (Marín-Garcia et al., 2013). These dimensions align closely with the CDIO Standards, particularly Standard 2, which emphasises learning outcomes tailored to professional and societal needs.

At the Faculty of Physical and Mathematical Sciences (FCFM) of the University of Chile, innovation is a cornerstone of the "Common Curriculum Plan" for early-year engineering students, aiming to prepare graduates with skills that effectively address technological and societal challenges. Three innovation courses (CD1100, CD1201, and CD2201) incorporate methodologies such as project-based learning (PjBL) and challenge-based learning (CBL), which consider group projects, hands-on activities, and interdisciplinary challenges designed to foster collaboration and innovation. For instance, CD1201 introduces students to real-world problems, requiring teamwork and critical thinking to propose viable solutions. This systematic alignment ensures that the curriculum supports the progressive development of innovation competence (Bravo-Cordova, 2021; Hélice, 2022). This set of courses has been taught to early-year students since 2018. Nevertheless, the faculty has not accurately measured the progress of innovation competence to improve educational programs continuously.

As highlighted by Guo et al. (2020), cognitive, behavioural measures, and self-perception—also referred to as self-reflection—are recognised as valid and meaningful dimensions for assessing student learning outcomes. The affective outcomes, such as students' perceptions of the benefits and experience of project-based learning (PjBL), are among the most frequently applied measures in higher education. This approach acknowledges that students' self-awareness and evolving understanding of their own abilities are key indicators of learning progression, particularly in the early stages of professional development. Therefore, this study aims to develop, design, and validate a tool focused on students' self-perceived competence in innovation, aligning with broader educational research that views self-reflection as a critical mechanism for both formative assessment and curriculum improvement (Guo, Saab, Post, & Admiraal, 2020).

The initial design of the tool for measuring the self-perception of students was adapted from the INCODE Innovation Competence Barometer (ICB) developed for the INCODE (Innovation Competencies Development) project of the European Union (Andreu-Andres et al., 2017). Later extended to FINCODA (Framework for Innovation Competencies Development and Assessment), which has been used to assess innovation competence in various educational contexts (Andreu-Andres et al., 2018; Guzmán-Soria et al., 2022; Marín-Garcia et al., 2013; Penttilä, 2012).

The 5-dimension survey used in the ICB (Peñalver et al., 2018) considers the competencies of (1) Creativity, (2) Critical Thinking, (3) Initiative, (4) Teamwork, and (5) Networking (Figure

2). This survey encompasses individual competencies (creativity, critical thinking, initiative), interpersonal competencies (teamwork), and network management (networking). These competencies have been validated in different iterations of this survey, with the most relevant being those of Marín-García et al. (2013), Butter & van Beest (2017) and Keinänen et al. (2018).

The competencies (Peñalver et al., 2018) are as follows:

1. Creativity: Thinking beyond existing ideas, rules, patterns, or relationships.
2. Critical Thinking: The ability to analyse problems, evaluate advantages and disadvantages, and assess the risks involved for a given purpose.
3. Initiative: The ability to make decisions or take actions to implement ideas that foster positive change and influence creative individuals and those responsible for executing the ideas.
4. Teamwork: The ability to work effectively with others in a group.
5. Networking: The ability to engage stakeholders outside the team.

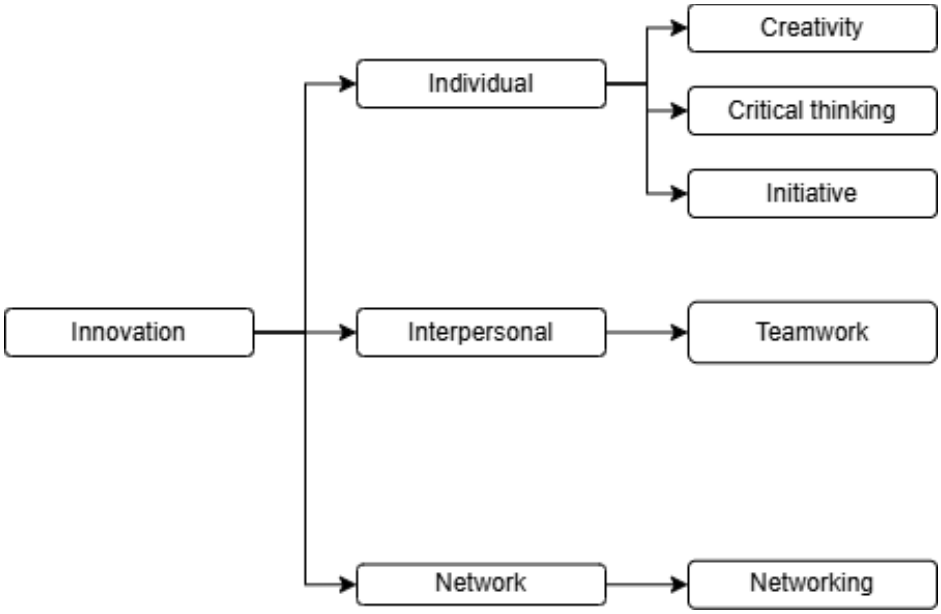


Figure 31. ICB innovation competency tool adapted from Marín-García et al.(2013) and Keinänen et al.(2018)

The survey employs a 5-point Likert scale (Vannette & Krosnick, 2017), with the lowest performance option on the left and the highest on the right (Youn et al., 2018). This makes option 1 "Strongly Disagree" and option 5 "Strongly Agree," providing a balanced middle option at 3 to facilitate decision-making during responses (Vannette & Krosnick, 2017). The ICB survey (Pérez-Peñalver et al., 2018) is detailed in Appendix A, separating the questions by innovation competencies.

The tool was modified and adapted to fit the local Chilean context, statistically validated, and implemented in the three innovation courses taught at the Faculty of Physical and Mathematical Sciences at the University of Chile to ensure relevance and applicability. This adaptation aimed to ensure that the instrument is aligned with the institution's educational objectives and relevant to the experiences of early-year engineering students.

METHODS

The tool design process was carried out in two stages: pre-pilot and pilot, which would allow the final survey to be designed and validated. After the validation process, the survey was applied at the beginning and end of a subsequent semester, resulting in 1005 responses across both applications. Comparative statistical tests were conducted to assess changes in students' perceptions of individual innovation competence and to validate the tool. Figure 1 describes the design and validation process to finalise the survey and its subsequent application in its definitive version.

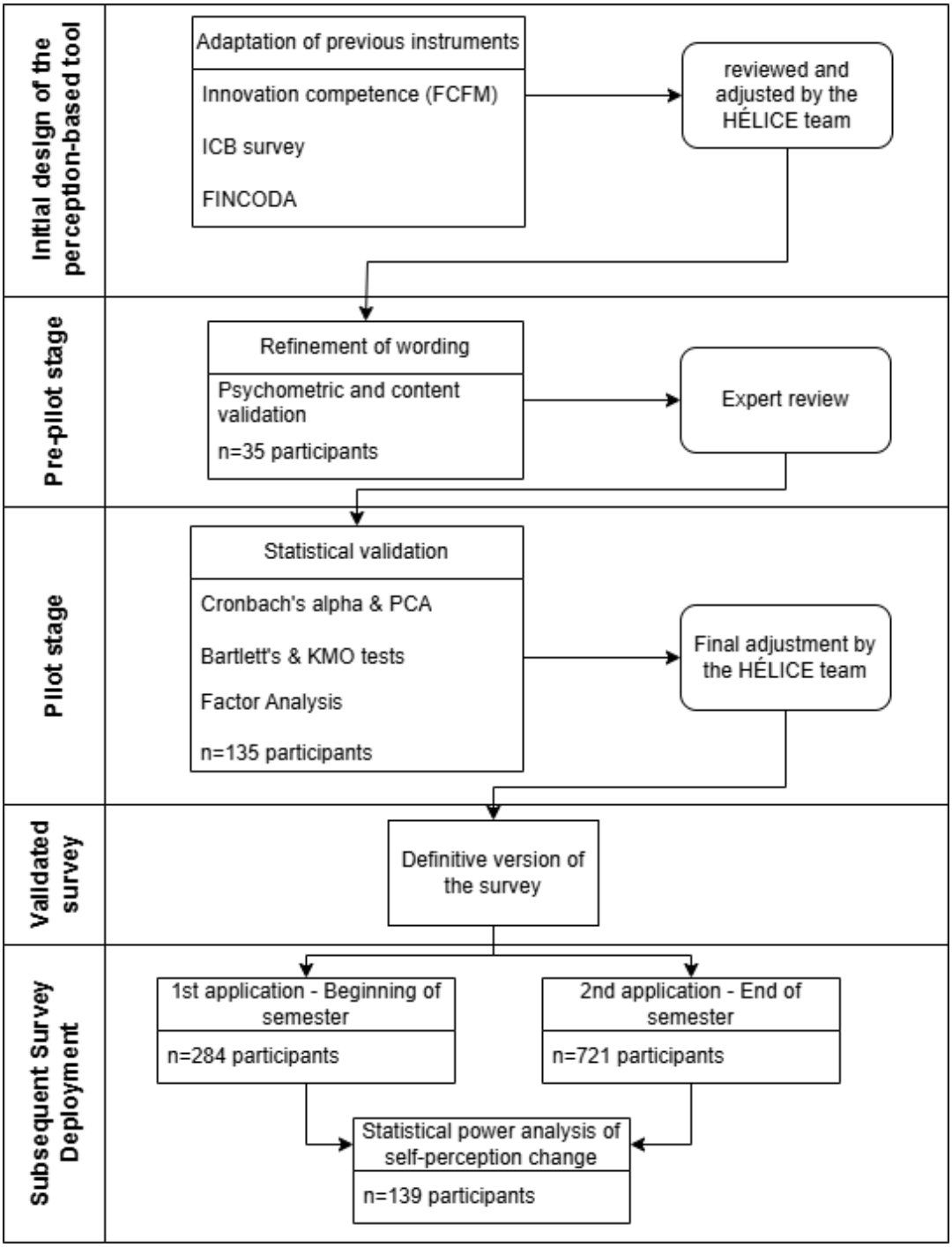


Figure 32. Diagram of the design, validation, and application process of the innovation competence perception-based tool

Pre-pilot stage

This phase focused on identifying issues related to the survey items' clarity, adequacy, and comprehensibility. As part of the pre-pilot stage, a psychometric validation of the phrasing of the questions was conducted by a committee of experts in the field (Aithal & Aithal, 2020), followed by implementation with a small sample of students (n=35) to gather feedback on question comprehension. A small sample size at this stage is justified as an exploratory effort to refine the instrument before broader implementation. This aligns with standard practices in survey development, where initial testing with limited participants identifies ambiguities or misinterpretations (Creswell, 2014).

The design of the pre-pilot survey was based on the current model of innovation competence in the engineering and science program defined for the first progression level of the competence (Hélice, 2022) and the ICB survey from the INCODE project with its underlying framework of five dimensions. The ICB survey was redesigned to adapt it to the context of the pre-pilot deployment at the University of Chile. This redesign included rephrasing several questions to clarify them for students recently admitted to higher education. Minimal changes were made to the original wording to prioritise the coherence of the survey without introducing additional bias. The original order was preserved to avoid introducing new biases due to order changes before subsequent analyses in this study (Elson, 2017). In any case, validation is required when applied in a context different from validated studies.

Pilot stage

After the pre-pilot stage, psychometric tests were conducted to evaluate the tool's internal consistency and structural validity. The refined survey was tested on a larger sample (n=135) to assess reliability and structural validity. Reliability tests were conducted on the survey for each dimension using Cronbach's Alpha for internal consistency, in which 1 indicates perfect internal consistency, above 0.9 is excellent, and above 0.7 indicates high consistency (Aithal & Aithal, 2020). Additionally, data and question quality were assessed using Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) measure (Kaiser, 1970).

Then, a factor analysis was used to identify the appropriate number of factors to separate the questions. This factor analysis was conducted using Principal Component Analysis (PCA) with Varimax rotation (Dilbeck, 2017), which produces orthogonal factors and a better explanation of the descriptive concept of each factor. This factor analysis allowed us to assign questions to each factor, thereby determining the final dimensions of the new survey.

Subsequent Survey Deployment

After the validation process, the survey was applied at the beginning and end of a semester, and it involved 1005 responses. Comparative statistical tests (Student's t-test) were conducted to evaluate student self-perception changes over time. These applications allowed for identifying statistically significant differences in perceived innovation competence. To further validate the survey, statistical power analysis was performed at each stage to ensure survey validity, revealing adequate power for detecting medium and large effect sizes (See Appendix E).

RESULTS

The results obtained from the pre-pilot and pilot stages and the subsequent deployment are presented below.

Pre-Pilot Stage Results

First, during the psychometric validation of the wording of the questions in the first version of the survey, experts reviewing these questions identified ambiguities in the phrasing of questions 1, 4, 5, 7, 8, 9, 11, 12, 19, and 21 (See Appendix A). Then, the survey was administered via the university's Learning Management System (LMS) "Ucampus" to n=35 participants. Among these, 19 were students, including 2 in the pre-admission stage to higher education, one second-semester student in the curriculum, and 16 third-semester students. This sample also included 16 teaching assistants from Level 1 innovation courses. Feedback was collected to adjust the questions' wording and improve the survey's overall structure. Six students highlighted difficulties in understanding the concepts in the questions within the Networking dimension, while seven teaching assistants raised similar concerns. No other comments were recurrent.

Pilot Stage Results

The refined survey was administered to a larger sample of early-year engineering students (n=135). The results of the improved version of the survey were used to assess the consistency of the initial tool, yielding the following Cronbach's Alpha reliability scores: 0.79 for the Creativity dimension, 0.79 for Critical Thinking, 0.80 for Initiative, 0.57 for Teamwork, and 0.83 for Networking.

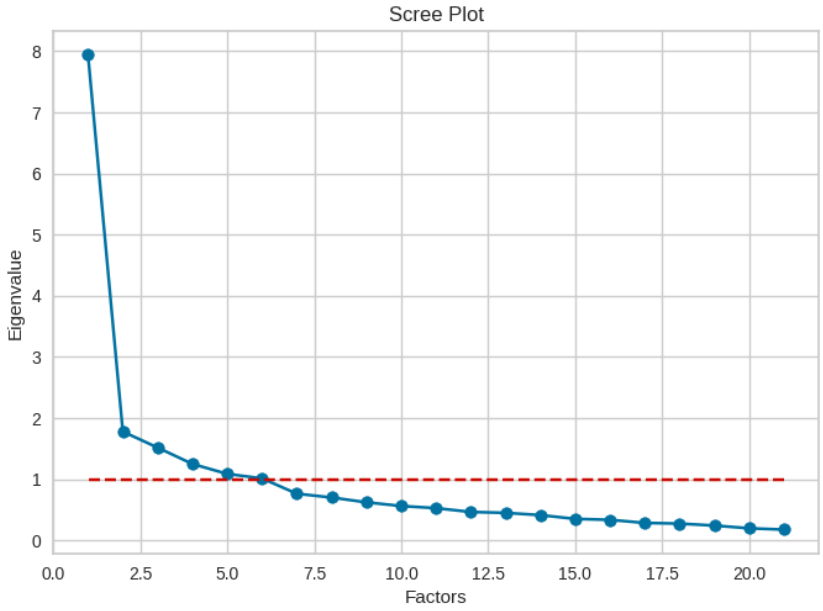


Figure 33. Eigenvalues by a number of factors

Subsequently, Bartlett's sphericity test indicated statistical significance for rejecting the null hypothesis of no correlation among the variables, with a chi-squared value of 1522.83 ($p < 0.001$). This confirmed that measured dimensions were independent; therefore, a factor analysis could be performed on the results. Also, the KMO adequacy test yielded a value of 0.87, above the recommended threshold of 0.70 (Kaiser, 1974) within the meritorious range, confirming that the data were appropriate for factor analysis. Principal Component Analysis (PCA) with Varimax rotation revealed six underlying factors corresponding to the original structure of the instrument, providing evidence of structural validity. The minimum variance threshold for factor analysis was achieved with six factors, as shown in Figure 3, which suggested the division of the dimension "Teamwork" into "Team Collaboration" and "Team

Moderation" in the survey. Also, question 7 showed low suitability (0.37) according to the communality's criterion (see Appendix B) and was subsequently excluded from the survey.

Then, factor analysis was applied to the new survey structure, and the results are shown in Table 1. Within this new survey, reliability scores for individual dimensions were as follows: 0.82 for Creativity, 0.81 for Critical Thinking, 0.82 for Initiative, 0.76 for Teamwork Subdimension 1 (referred to as Team Moderation), 0.76 for Teamwork Subdimension 2 (referred to as Team Collaboration), and 0.83 for Networking, indicating high internal consistency across all dimensions.

Table 13. Factor loadings and communalities for the final survey

Question	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Communality
1			0,845				0,797
2			0,676				0,557
3			0,601				0,563
4	0,583						0,476
5	0,687						0,584
6	0,691						0,666
8	0,589						0,497
9		0,679					0,624
10		0,619					0,554
11		0,408					0,427
12		0,514					0,511
13					0,639		0,503
14					0,767		0,720
15					0,511		0,574
16		0,466					0,518
17						0,680	0,574
18						0,760	0,674
19				0,814			0,786
20				0,503			0,552
21				0,733			0,730

Survey Designed for Deployment

Due to the lack of clarity observed in the pre-pilot stage, two brief attention check questions were included within the intermediate sections of the survey. Abbey and Meloy (2017) state that multiple attention checks increase inattentive respondents' capture rate. Therefore, these questions aimed to improve response quality without compromising deliberate response behaviour (Kung et al., 2018). The questions were one directed type, and one instructed manipulation type. These were: “The following question is simple, and you must answer by selecting the 'Strongly Disagree' option: my work team for this semester's course has 20

members. It is noted that the composition of teams in Level 1 innovation courses has a maximum of 6 members, without exception.

Finally, a closing question section was included at the end of the survey to collect additional information that respondents may wish to provide. The definitive version of the survey is presented in Appendix D.

Subsequent Survey Deployments

The results of the t-tests revealed statistically significant improvements in students' perceptions of their innovation competence. Significant improvements were detected in several dimensions, particularly creativity, teamwork, and critical thinking. However, the students did not perceive changes in Team Collaboration.

Detailed results of the power analysis are provided in Appendix E. The power analysis results allow the identification of medium-sized effects (0.5) with a power of 0.54 and 0.98 in the pre-pilot and pilot stages, respectively, and large-sized effects (0.8) with a power of 0.91 and 1.0, respectively.

These findings suggest that the tool is validated and can detect meaningful changes in self-perceived innovation competence over time.

DISCUSSION

This study presents a validated tool for measuring self-perception aspects of innovation competence among first-year engineering students, providing a framework for assessing and enhancing critical skills such as creativity, critical thinking, initiative, teamwork, and networking. The tool's development and implementation align with the CDIO Standards, ensuring relevance to academic and professional contexts.

The iterative design process, supported by expert reviews and pilot testing, enabled the creation of a culturally and contextually relevant instrument. Based on the findings from the pre-pilot, the definition of terms was essential to ensure a proper understanding of the survey questions. Some questions were often characterised by their generic nature, ambiguity, lack of clarity, and unfamiliar terminology for the first-year students, making them challenging to comprehend and answer accurately. Mainly, concepts like "networking" were unknown to respondents, which triggered the final survey to be organised into sections.

Each section represents a dimension of the innovation survey to be implemented. To facilitate comprehension, definitions for each dimension were included within the survey to contextualise the questions and clarify what each dimension seeks to measure.

In addition, the pilot stage revealed the tool's validation for efficacy in measuring the self-perception of innovation competencies of the target population. Factor analysis during this stage required subdivision of the teamwork dimension into “Team Collaboration” and “Team Moderation” for a better assessment. This adjustment was based on the results of the minimum variance threshold that indicated six factors.

Results from the large-scale implementation phase demonstrated the tool's capacity to evaluate the dimensions within self-perception innovation competencies. These results offer actionable insights for targeted curricular improvements. For example, incorporating project-based learning experiences for improving the Team Collaboration aspects.

So, combining qualitative-expert judgment and quantitative measurements allowed to define an appropriate survey for self-perception of the innovation competency. Additionally, integrating project-based and challenge-based learning methodologies provides a robust foundation for fostering innovation within the curriculum. Future iterations could expand on these practices by incorporating digital platforms for real-time data collection and analytics, enhancing both instructional strategies and student engagement (Hélice, 2022). Additionally, exploring interdisciplinary applications of the tool in engineering and other domains will contribute to the broader understanding of innovation competence in higher education. Future research underscores the importance of embedding systematic evaluation frameworks within engineering curricula to cultivate graduates capable of addressing complex challenges in a rapidly evolving world.

CONCLUSIONS

The statistical methods for validating the survey at different stages show that the procedure was sufficiently robust to produce a context-aligned tool for evaluating self-perception innovation competencies among early-year engineering students at the University of Chile. The study also highlights the efficacy of the adapted ICB tool in offering actionable insights for curriculum development, offering a basis for curricular adjustments that can better align training with desired learning outcomes. By considering the particularities of the local context, this study contributes to the continuous improvement of innovation education and aligns academic training with the demands of the labour market and global challenges.

Future work will further analyse the results of the deployment stage to evaluate the progression of innovation competence over time in order to adjust education programs in the short term. Also, this study will look forward to combining students' self-perception with cognitive outcome measurements and behavioural outcomes to deeply understand the learning process of innovation in an engineering environment that allows the development of a robust but context-specific tool for measuring students' learning process and improving innovation courses.

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APPENDIX A: PRE-PILOT SURVEY

Creativity

1. I make proposals that meet the demands of the task.

2. I suggest new or original ideas to solve problems.

3. I propose new ways to materialise ideas.

11. I make bold but justified decisions.

15. I actively participate to ensure the group achieves its goals.

Critical Thinking

4. I critically evaluate what is required for tasks.

5. I understand the causal relationships between the different aspects of the task.

6. I am able to view a task from different perspectives.

7. I use available resources skilfully.

8. I am able to anticipate upcoming events.

18. I can resolve conflicts within a group to achieve a common goal.

Initiative

9. I show enthusiasm for what I do.

10. I work persistently to achieve goals.

12. I orient the task towards the final objectives.

16. I am capable of taking the initiative without being prompted.

Teamwork

13. I consider the viewpoints of group members.

14. I am capable of collaborating.

17. I am capable of motivating others to act.

Networking

19. I can use external communication networks.

20. I am capable of working in multidisciplinary environments.

21. I am capable of networking (establishing contact networks).

APPENDIX B: COMMUNALITIES FOR SURVEY ANALYSIS WITH 21 QUESTIONS.

Table 14. Communalities for survey analysis with 21 questions

Question	Communality
1	0,843
2	0,525
3	0,557
4	0,435
5	0,565
6	0,685
7	0,374
8	0,530
9	0,649
10	0,543
11	0,426
12	0,513
13	0,473
14	0,735
15	0,580
16	0,528
17	0,572
18	0,677
19	0,788
20	0,546
21	0,718

APPENDIX C: FACTOR LOADINGS AND COMMUNALITIES FOR THE FINAL SURVEY

Table 15. Factor loadings and communalities for the final survey (complete)

Question	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Communality
1	0,178	0,155	0,845	0,134	0,041	0,075	0,797
2	0,150	0,120	0,676	0,203	0,097	0,106	0,557
3	0,283	0,198	0,601	0,162	0,153	0,179	0,563
4	0,583	0,277	0,114	-0,039	0,023	0,205	0,476
5	0,687	0,197	0,156	0,107	0,189	0,009	0,584
6	0,691	0,266	0,201	0,216	0,172	0,005	0,666
8	0,589	0,086	0,201	0,246	0,158	0,122	0,497
9	0,204	0,679	0,158	0,262	0,095	0,129	0,624
10	0,289	0,619	0,152	0,141	0,161	0,130	0,554
11	0,258	0,408	0,220	0,220	0,300	0,075	0,427
12	0,360	0,514	0,202	0,056	0,152	0,221	0,511
13	0,241	0,065	0,067	0,156	0,639	0,050	0,503
14	0,038	0,207	0,080	0,125	0,767	0,253	0,720
15	0,240	0,409	0,156	0,049	0,511	0,246	0,574
16	0,127	0,466	0,073	0,131	0,272	0,432	0,518
17	0,044	0,141	0,104	0,215	0,175	0,680	0,574
18	0,144	0,157	0,149	0,121	0,113	0,760	0,674
19	0,156	0,114	0,164	0,814	0,157	0,180	0,786
20	0,294	0,206	0,197	0,503	0,345	0,104	0,552
21	0,099	0,248	0,261	0,733	0,083	0,212	0,730

APPENDIX D: FINAL SURVEY DESIGN

Introduction Text to the Survey

Broadly speaking, innovation refers to a new or improved product or process that significantly differs from what existed before. To innovate, an individual must use their competence or capacity to innovate, which is fundamental to their development in the context of the Engineering and Sciences program and plays a pivotal role in society.

To complete this self-assessment, you will evaluate how you perceive your ability to innovate in response to different statements. You can position your answer anywhere on a scale ranging from Strongly Disagree to Strongly Agree.

The honesty of your responses will provide important information for the continuous improvement of the Common Plan innovation courses, as this instrument is designed to measure the progress of innovation competence development throughout the study program.

Control Questions

- Have you participated in any innovation or entrepreneurship courses or activities outside the faculty? (Yes / No)
- Are you participating in any innovation or entrepreneurship courses or activities outside the faculty this semester? (Yes / No)
- Do you feel that your personal environment, outside of your studies, encourages learning or creativity? (Yes / No)
- Do you have access to technological resources such as the internet, a computer, or a smartphone? (Yes / No)
- Have you used online platforms to learn something on your own? (Yes / No)
- The following questions are simple, and you must respond by selecting the "Strongly Disagree" option.

Creativity

Understanding creativity as the ability to think beyond existing ideas, rules, patterns, or relationships, please answer the following questions:

1. I propose novel ideas that meet the demands of the task.
2. I suggest new or original ideas to solve problems.
3. I propose creative ways to implement ideas.

Critical Thinking

Defining critical thinking as the ability to analyse problems, evaluate advantages and disadvantages, and assess the risks involved for a purpose, please answer:

4. I critically analyse and evaluate what tasks require.
5. I understand how the different aspects of a task interact and relate.
6. I can view a task from different perspectives.
8. I can anticipate the impacts and scope of decisions.

Initiative

Understanding initiative as the ability to make decisions or take action without receiving an external order or instruction:

9. I show initiative to act.
10. I work persistently to achieve goals.
11. I dare to make decisions but base them on sound reasoning.
12. I execute tasks oriented towards final objectives.
13. I am capable of taking the initiative without being prompted.

Team Collaboration

By team collaboration, we refer to the ability to work effectively with others within your team.

14. I consider the viewpoints of group members.
15. I am capable of collaborating.
16. I actively participate to ensure the group achieves its goals.

Team Moderation

By team moderation, we refer to the ability to guide and facilitate the team's internal dynamics.

17. I am capable of motivating others to act.
18. I can resolve conflicts within a group to achieve a common goal.
19. My team for this semester’s course consists of 20 members.

Networking

Understanding networking as establishing connections with people beyond your team who are willing to contribute information, resources, or opportunities for a purpose, please answer the following questions:

20. I can use networks beyond the team.
21. I can interact and work in multidisciplinary environments.
22. I am capable of building networks beyond the team.

Closing Questions

- In your opinion, what is innovation useful for? (Open Response)
- How have the innovation courses helped you? (Open Response)

Feedback

- What did you think of the survey? (Open Response)

APPENDIX E: SAMPLE SIZE DETERMINATION

Given the broad universe of students and the unknown expected response rate with the deployment methods applied, the sample size was not determined ex-ante. However, the responses obtained were sufficient to achieve significant statistical power for the expected effect sizes under study.

As each stage was deployed, Table 4 shows that the statistical power test (alpha = 5%) allows the identification of medium-sized effects (0.5) with a power of 0.54 and 0.98 in the pre-pilot and pilot stages, respectively, and large-sized effects (0.8) with a power of 0.91 and 1.0, respectively. The pre-pilot stage was designed to identify significant issues related to the clarity of the wording, and the review process was considered adequate—meanwhile, the pilot stage aimed to detect more minor effects.

For subsequent semester deployments, the most relevant factor is the number of respondents in both instances, which is similar to the number of respondents in the pilot stage. Therefore, it allows for identifying effects of similar magnitude, particularly with a power of 0.99 for medium-sized effects and 1.0 for large-sized effects.

Table 16. Statistical power for different effect sizes across deployment stages

Effect size	Pre-pilot (n=35)	Pilot (n=135)	First application (n=284)	Second application (n=721)	Change in answers (n=139)
0.1	0.070	0.130	0.221	0.475	0.132
0.2	0.131	0.374	0.662	0.967	0.383
0.3	0.236	0.690	0.946	1.000	0.703
0.4	0.378	0.906	0.997	1.000	0.914
0.5	0.541	0.984	1.000	1.000	0.986
0.6	0.697	0.998	1.000	1.000	0.999
0.7	0.823	1.000	1.000	1.000	1.000
0.8	0.910	1.000	1.000	1.000	1.000
0.9	0.960	1.000	1.000	1.000	1.000
1.0	0.985	1.000	1.000	1.000	1.000