CHEMICAL ENGINEERING CURRICULUM REDESIGN FOR INTEGRATING UN SDGS USING CDIO

Ai Ye OH, Yunyi WONG, Katerina YANG

School of Chemical & Life Sciences, Singapore Polytechnic

Sin-Moh CHEAH

Department of Educational Development, Singapore Polytechnic

ABSTRACT

This paper shares the process and outcomes of the efforts from the Diploma in Chemical Engineering (DCHE) offered by Singapore Polytechnic (SP) in integrating the Common Core Curriculum (CCC) using the CDIO Framework. The CCC is an institutional-wide requirement applicable for all SP programs; and uses the United Nations Sustainable Development Goals (UN SDGs) as context of learning generic, broad-based skills and attitudes needed in today's world. This was introduced into the 3-year DCHE program in Academic Year 2022/2023. The authors used the 12 core CDIO Standards to carry out standard-by-standard evaluation of the extent of sustainable development coverage in the existing DCHE curriculum. The paper presents the opportunities where CCC modules could be integrated into the DCHE curriculum to build upon existing skills and attitudes with focus on key areas of chemical engineering and sustainable development as recommended by the Institution of Chemical Engineers, UK (IChemE) that accredits the DCHE program. The paper then explains how the context for learning is set and how selected CCC modules and DCHE modules were paired, forming an integrated curriculum that further strengthens the existing spiral curriculum. New learning activities were created and existing activities were re-designed to integrate the generic skills taught in CCC modules into DCHE modules in the context and applications in chemical engineering. The paper then shares the findings from students on their experience in the new DCHE-CCC way of learning. A quantitative survey was administered for students to rate their learning experiences with an open-ended question for them to express the challenges they faced when they had to apply the skills. Focus group discussions with students were facilitated so that the authors could understand these challenges better. The findings were generally positive with practical comments that form the areas of improvement to address the challenges. Finally, the paper shares future plans for the DCHE course to review the coverage of sustainability in other modules through an integrated curriculum approach.

KEYWORDS

Chemical Engineering, Sustainable Development, Integrated Curriculum, CDIO Standards: 1, 2, 3 and 7, CDIO Optional Standard: 1

INTRODUCTION

The Diploma in Chemical Engineering (DCHE) adopted the CDIO Framework as the basis for redesigning its curriculum since 2007. Over the years many changes had been made to align the curriculum with key stakeholder requirements, namely the Singapore Government, Singapore Polytechnic (SP) and the Institution of Chemical Engineers, UK (IChemE) that accredits the program. Its latest course structure is one for spiral curriculum, with effect from Academic Year (AY) 2018/2019, is a direct response to the introduction of the Singapore SkillsFuture Initiative (Cheah & Yang, 2018).

Among the many changes that were made to the DCHE curriculum includes the teaching of sustainable development. In fact, the first effort at integrating education for sustainable development (ESD) started in AY2011/2012, when SP introduced design thinking into the institution. The CDIO Framework had been used as the basis for integrating ESD into the DCHE curriculum (Cheah, 2014; Yang & Cheah, 2014; Cheah, Yang & Sale, 2012; Ng & Cheah, 2010).

The current DCHE course structure features a "dual pathway" of applications of chemical engineering principles: one is the "traditional" chemical process operations in chemical processing industries, and the other is the more recent application in chemical product design. This is the DCHE strategy of achieving what is known as "dual-impact learning" in the CDIO Approach: that students simultaneously learn the domain knowledge at the same time also develop the necessary skills and attitudes in applying the knowledge (Crawley, et al, 2007). Sustainable development are thus integrated into both pathway, with greater emphasis in chemical product design pathway, as this is designed to support Year 3 Final Year Project (FYP), also known as the Capstone Project.

DCHE, Common Core Curriculum and ESD

In AY2020/2021, SP Management announced that all diplomas will have to include Common Core Curriculum (CCC), and 2 diplomas namely Diploma in Optometry and Diploma in Aeronautical Engineering will do the pilot in the same year. The CCC is designed to prepare SP students for a disruptive world that is ever-changing. Technological disruptions have created new and increasingly sophisticated job roles, hybrid job roles which require graduates to have diverse skill sets. These in-demand skills include both emerging digital skills and human skills in artificial intelligence (AI), collaboration and persuasion, and critical thinking. The CCC provides an integral and inter-disciplinary learning experience to address the wicked problems of the world framed by the United Nations' Sustainable Development Goals (UN SDGs), which run thematically across the 10 CCC modules. The details are published by Cheah, Lim and Chao (2022).

The first module in CCC introduced into Year 1 Semester 1 is *Thinking Critically about the UN SDGs*, and it sets the context for learning. Only selected modules from CCC are required for pairing with the diploma's domain core modules. Each diploma is at the liberty to decide how best to pair its domain core modules with the CCC modules, to suit the diploma's own learning context. Other CCC modules, e.g. *Artificial Intelligence and Its Impact* can be delivered as standalone module. DCHE introduced its revised curriculum integrating CCC in AY2022/2023 is shown in Figure 1.

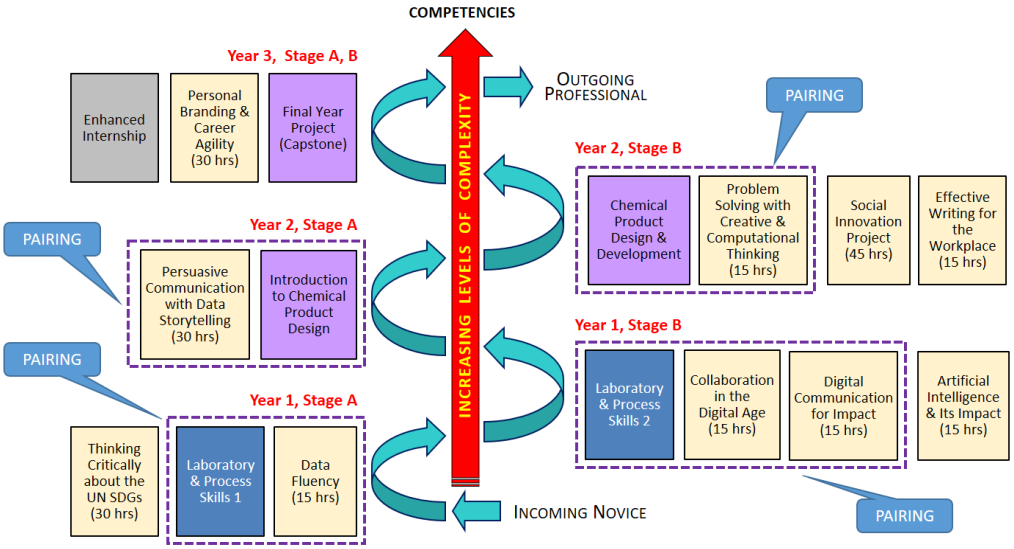


Figure 1. Paired Core Modules in the DCHE Spiral Curriculum Course Structure

USING CDIO CORE STANDARDS TO GUIDE DESIGN OF ESD IN DCHE

The 12 core CDIO Standards were used to carry out a standard-by-standard evaluation of to what extent, elements of sustainable development had already been covered in existing DCHE curriculum; and what else needs to be done. The result is shown in Table 1. Note that in this table, the term "CCC skills" is used to denote skills and attitudes to be developed via the CCC modules.

Table 1. General Guiding Principles for Curriculum Design for ESD using CDIO and CCC

Core Standard No.	Curriculum Design to include Sustainable Development
1. The Context	Align the context for learning sustainable development within a given disciplinary setting is with the focus area(s) of key stakeholders that the diploma is serving. All diplomas can take reference from the Singapore Green Plan 2030, which spelt out many initiatives and targets grouped under 5 themes of City in Nature, Energy Reset, Sustainable Living, Green Economy, and Resilient Future. Professionally accredited diploma can also benefit from guidance from the accreditation body, in specific areas of interest to the discipline.
2. Learning Outcomes	Connect domain-specific learning outcomes with requirements from CCC's more generic learning outcomes. These CCC learning outcomes can serve as "building blocks" to develop higher-order skills and attitudes that are needed in ESD. Together with the CDIO Syllabus, identify other skills and attitudes that are needed to complement the generic CCC skills for delivering the domain area learning outcomes; in selected domain core modules and suitably contextualized to provide the desired proficiency levels.
3. Integrated Curriculum	Ensure the progressive development of skills and attitudes needed for sustainable development via appropriate pairing with CCC. This means the outcomes of a given pairing should serve to enhance and extend learning beyond the paired modules. The notion of "deliberate practice" (Ericsson, 2008) would suggest that students be exposed to issues of sustainable development in other core modules. This will lead to the systematic development of skills from both horizontal integration (i.e. serving as reinforcement) and vertical integration (i.e. serving to level up) students' competencies in addressing sustainability issues.

Table 1. (continued)

Core Standard No.	Curriculum Design to include Sustainable Development
4. Introduction to Engineering	Introduce the context of learning about specific UN SDGs relevant to the discipline, through Year 1 Semester 1 module such as *Introduction to Chemical Engineering* that introduces students to the profession. This module can be also "unofficially paired" with "introductory" standalone CCC module *Thinking Critically about the UN SDGs*.
5. Design-Implement Experiences	Review existing curriculum on the use of project-based learning in core modules – either as standalone modules in various years of study; or via a group of modules in a deliberately designed "project spine" across stages of study from Year 1 to Year 3. During the review process, one can identify opportunities to include selected UN SDGs as the context for project work. The CCC module *Sustainable Innovation Project* itself is a multi-disciplinary project will remain as standalone; to enable students from different courses to work together in a multi-disciplinary manner.
6. Engineering Learning Workspaces	Make existing learning workspaces more "conducive" to support discussing about sustainability issues, through simple efforts such as highlighting the facilities' on-going efforts on energy-saving, water conservation, use of less chemicals, waste recycling, etc. Good management practices, such as ISO 14001 should be integrated as part of as laboratory / workshop briefing; or day-to-day operations where applicable, for example housekeeping after the conclusion of each experiment.
7. Integrated Learning Experiences	Review existing learning activities (lab experiments, assignments, etc) for opportunities to include added emphasis on sustainable development within the disciplinary domain. These integrated learning experiences should take into considerations the skills and attitudes already introduced in CCC. They should preferably address several UN SDGs using the same learning context for an activity, to reflect the interconnectedness of these 17 goals; and to engage students in using a range of key competencies needed for sustainable development.
8. Active Learning	Explore ways to use active learning in classroom settings. These should focus on peer learning in a collaborative manner with the help of technologies (such as Jamboard or Google Docs) to elicit different viewpoints from students in the context of appropriate UN SDGs to develop key competencies needed for sustainable development.
9. Enhancement of Faculty Competence	Provide professional development programs that focus on developing lecturers' competency to teach and facilitate development of various CDIO skills in the context of sustainable development, such as emphatic thinking, systems thinking, transdisciplinary thinking, etc
10. Enhancement of Faculty Teaching Competence	Provide professional development programs that focus to develop competencies in providing integrated learning experiences, using active and experiential learning methods, and assessing student development of skills and attitudes in the context of sustainable development, as described in Standards 7, 8 and 11.
11. Learning Assessment	Use "Constructive Alignment" to ensure "shared" assessments between the paired CCC modules and domain core modules are designed such that the assessments in domain core are always aligned to the learning outcomes from CCC modules (see also Standard 2) in any learning tasks that engage students in developing sustainable development competencies.
12. Program Evaluation	Carry out review of integration of sustainable development in the curriculum via the usual self-evaluation process using the CDIO Core Standards; to supplement the usual module review and course review; with a view of continual improvement to enhance sustainability issues. Identify best practices seen in modules consistent with each standard's rubrics.

The remaining paragraphs in this section provide examples that elaborates on how Standards 1, 2 and 3 are applied to guide the integration of sustainable development into Year 1 of the DCHE curriculum via pairing with CCC using the design guidelines based on the CDIO Framework presented in Table 1.

The approach to designing an Integrated Learning Experience (CDIO Core Standard 7) for a core module is shared in the next section. The section after that provides examples of the learning activities in DCHE Year 1 curriculum that involves the pairing with CCC.

CDIO Core Standard 1: Setting the Context for Sustainable Development

DCHE had introduced chemical product design into its curriculum, focusing on sustainable development when it adopted CDIO to redesign its curriculum (Cheah, 2014; Yang & Cheah 2014). DCHE had already aligned its focus for FYP, based on the IChemE focus areas on challenges in Energy, Food & Nutrition, and Water as highlighted in its Chemical Engineering Matters, now in its 3rd Edition. (IChemE, 2016). It was therefore quite straightforward for DCHE to identify which UN SDGs to focus its coverage on. The work that needs to be done is to explicitly link the IChemE focus areas to the relevant UN SDGs to make clear to students how learnings from the CCC can be linked to what they will learn in DCHE. This can be further contextualised to focus on the Singapore's own effort as outlined in the Singapore Green Plan 2030 in general, and chemical industry in particular, based on the sustainable development initiatives at Jurong Island (EDB, 2021).

CDIO Core Standard 2 and CDIO Syllabus: Complementary with CCC Learning Outcomes

The desired outcomes from ESD had been extensively reviewed (Cheah, 2021). The knowledge, skills and attitudes needed to support sustainable development had been identified by various authors such as Lazano, et al, 2017; Scarff-Seatter & Ceulemans, 2017; Barth, et al, 2007). In the current thinking on ESD, the outcomes to be achieved is that of third-order, transformative learning (Mezirow, 2003; Sterling, 2011). These learning outcomes can be written using the CDIO Syllabus, which is aligned to the UNSECO Framework (Rosen, et al, 2019).

An important point to note here is the "competency in sustainable development" is a high-order competency that is taken as the aggregation and build-up from a number of foundational skills and attitudes. The human skills and digital skills covered in the CCC modules provide some of these foundational skills and attitudes, complementing other skills and attitudes covered in the DCHE syllabus such as growth mindset, hypothesis testing, critical thinking, etc. Systems thinking in particular – as covered in CDIO Syllabus version 3.0 Part 2.3 – is very important in sustainable development as it emphasized thorough consideration of decisions made today that are seemingly beneficial but may adversely impact the environment or society into the future; in what is termed "unintended consequences".

CDIO Core Standard 3: Identifying pairing with CCC

In the CDIO integrated curriculum, and in particular for the DCHE spiral curriculum, requires thoughtful "pairing" with selected CCC modules, via both horizontal integration (reinforcement across several modules in the same stage) and vertical integration (levelling up across modules from stage to stage) integration to progressively develop knowledge, skills and attitudes required. Since the CCC is conceptualised to offer each diploma the flexibility of deciding on its own pairing, DCHE selected domain core modules to pair with which CCC modules based on the objective of always to strive for "dual-impact learning" – a hallmark of CDIO-type curriculum.

In the context of ESD in DCHE, the learning of sustainability principles can be used in both chemical plant operation and chemical product design using the same set of chemical engineering principles (Cheah, 2021). The pairing selection is therefore based on how the CCC modules can strengthen existing coverage of skills and attitudes in the DCHE curriculum

similar to how the Critical Core Skills of the Singapore Skills Framework are to be used: i.e. “Skills to Build Skills”.

For example, in Year 1 Semester 1, *Data Fluency* is paired with *Laboratory and Process Skills 1 (LPS1)*, because the DCHE domain core deals with challenges in conducting laboratory experiments and working in pilot plants, and both require skills in data handling. Furthermore, big data had earlier been pin-pointed as a focus area for DCHE when we reviewed our curriculum in response to the needs of Skills Framework for the Energy and Chemicals Sector with consideration to the impact of Industry 4.0 on the chemical processing industry (Cheah & Yang, 2018). Having the right kind of data (in terms of reliability and validity) is important before such data can be used.

THE CDIO WAY TO INTEGRATE ESD INTO CURRICULUM WITH CCC

The steps below describe a simplified approach to integrate sustainable development into a curriculum, i.e. at the diploma-level. The objective is to set high-level learning outcomes at the course level – often captured in the Course Aims and the sub-aims:

1. Ascertain the context for learning by referring to requirements of key stakeholders for your diploma with respect to sustainable development and identify several appropriate UN SDGs.
2. Write some high-level outcomes for the desired transformative learning, based on the selected UN SDGs and focus areas of sustainable development of your course.
3. Identify the competencies (knowledge, skills and attitudes) needed to support sustainable development in the context and outcomes identified above.

The required competencies will have to be gradually developed via an integrated curriculum (CDIO Core Standard 3). This paper will not report on the approaches to integrating sustainable development via projects (i.e. CDIO Core Standard 5 Design-Implement Experiences), as this had been addressed elsewhere by Yang & Cheah (2014) on DCHE’s “project spine”. The steps described below follows from the steps above in translating the context and outcomes desired at the course-level down into learning tasks (known as integrated learning experiences, as per CDIO Core Standard 7) in a module that was paired with one or more CCC modules. The DCHE Course Management Team made the decision on how best to pair the CCC modules with the diploma’s own domain core modules. These domain core modules are the ones that are most amenable to include issues related to sustainable development. In other words, they provide the natural context for inclusion of the selected UN SDGs while remembering that one domain core module can be paired with more than one CCC modules.

1. Identify at least one UN SDG that fits the topics covered in the domain core module.
2. Identity a plausible real-world scenario involving sustainability issues targeted by the selected UN SDG(s), and write a brief description of the scenario.
3. Identify the competency (knowledge, skills and attitudes) needed for the scenario and write the learning outcomes using suitable taxonomy (e.g. Bloom) into the module syllabus.
4. Identify any prior knowledge acquired earlier, as well as skills and attitudes developed earlier that are needed to support the desired competency.

5. Develop the assessment scheme (CDIO Core Standard 11) that include the required evidence of learning; and check for constructive alignment.
6. Prepare scaffolding that support the development of the desired competency, e.g. performance rubrics.

Note that the approach suggested above is equally applicable to modules that are not being paired with CCC. In fact, it can be envisioned that to effectively develop the necessary sustainability competency as one of the desired graduate attributes, significant numbers of such integrated learning experiences need to be included into a 3-year diploma program.

The remainder of this paper is devoted to such a discussion, focusing on work done in Year 1 DCHE. As mentioned in earlier section, the revised DCHE curriculum featuring CCC was introduced in AY2022/2023; with the pairing as shown in Figure 1.

WORK DONE IN FIRST YEAR DCHE PAIRED MODULES

Key features in the pairing of DCHE core modules with CCC module are shown in Table 2 for *Data Fluency* paired with *LPS1* for Semester 1, Year 1; and Table 3 for *Digital Communication for Impact* and *Collaboration in the Digital Age* paired with *Laboratory & Process Skills 2 (LPS2)* for Semester 2, Year 1.

Table 2. Pairing for DCHE Year 1 Semester 1 Curriculum

CCC: *Data Fluency* – Module Learning Outcomes
• Show examples on the prevalent use of (big/large) data in tackling UN SGDs • Formulate specific data questions that exhibit aggregated perspectives by using words like typically, generally, on average, etc • Illustrate the different data collection methods (archives, surveys, experiment, etc) • Join and clean data sets from multiple sources • Classify data into qualitative and quantitative • Explore data using different visualizations (Card, Bar, Pie, Word cloud) • Explain the aggregated view of data using various numerical summaries (e.g., Sum, Average, Min, Max, CountD, Count, Standard Deviation, Median)
DCHE: *Laboratory & Process Skills 1* – Assignment Learning Outcomes
• Investigate the type of flowmeter used in household for measuring water consumption • Explain the working principles of 2 different types of water flowmeter used in the chemical industry • Explain the importance of understanding the working principles of various flowmeters • Compare and contrast between flowmeters used in household vs. industry • Explain feasibility of replacing household flowmeter with industrial flowmeter
Assignment in Brief: • UN SDG 6: Clean Water and Sanitation • Students used the water consumption in Singapore households data and prepared a dashboard using PowerBI to identify possible trends with possible factors such as housing types and number of household members; and draw insights
Assessment: • Students were assessed based on how well they understood the working principles of flowmeters, how the appropriate flowmeters were selected and used to measure water consumption in Singapore households versus those used in the industry.

Table 3. Pairing for DCHE Year 1 Semester 2 Curriculum

CCC: *Digital Communication for Impact* – Module Learning Outcomes
• Identify the key differences between digital and face-to-face communication • Compare and contrast digital communication platforms / tools and build an understanding of their benefits and limitations • Examine the different building blocks of impactful digital communication • Design and apply key principles when crafting impactful digital communication (written, visual, audio and video) to engage and inspire your target audience • Discuss what it means to be a responsible Digital Citizen • Demonstrate an understanding of and respect for the rights and obligations of using and sharing intellectual property • Describe strategies to cultivate and manage digital identity, personal data and privacy • Demonstrate positive, safe, legal and ethical behaviour when using digital communication
CCC: *Collaboration in the Digital Age* – Module Learning Outcomes
• Identify personal strengths and weaknesses • Identify own roles and responsibilities and their contributions towards the achievement of team goals • Set SMART individual and team goals to achieve project outcome • Apply effective communication techniques to encourage participation and collaboration in a team (F2F/digital) • Demonstrate positive digital body language and EQ throughout the online interaction • Accept and provide feedback in a considerate and constructive manner • Use simple project planning and collaboration tools to manage team projects
DCHE: *Laboratory & Process Skills 2* – Assignment Learning Outcomes
• Classify activities for a project in a given context to the stages of Conceive-Design-Implement-Operate • Understand the functions of key departments in a typical company in the Energy & Chemicals Sector, and the job roles in and the responsibilities of these departments • Identify the key departments that will be involved in the activities for a project in a given context • Identify key factors of consideration about a project in a given context • Relate the functions and responsibilities in key departments to the factors that need to be considered for a project in a given context • Compare and contrast the use of seawater vs cooling water as cooling medium in a given context.
Assignment in Brief: • UN SDG 14: Life Below Water • Students worked effectively as a team to identify the roles and responsibilities of departments involved in the design, installation and operation of a heat exchanger to cool a hot product stream. Then, they collaborated on an online platform to study the pros and cons of the use of cooling water or seawater as the cooling medium for the heat exchanger, and draw insights to create a video for a digital communication platform to educate members of the public.
Assessment: • Students were assessed on the effectiveness of their teamwork, quality of online discussion, provision of relevant and sufficient information needed to communicate intent to target audience in video created and how well key principles of impactful digital communication were used (CCC), thoroughness and depth of consideration when deciding between use of cooling water or seawater as cooling medium for the heat exchanger.

DISCUSSION OF FIRST YEAR STUDENTS' LEARNING EXPERIENCE

In this first run of CCC in DCHE, a survey designed to evaluate the students' learning experience in the paired modules with quantitative questions and an open-ended question was administered to 60 students from the AY2022/2023 cohort in the DCHE course. Participation in the survey was on a voluntary basis and students' names were not collected to retain anonymity during analysis of the survey results. A focus group discussion was subsequently conducted with students randomly selected from the three classes surveyed to triangulate the survey results.

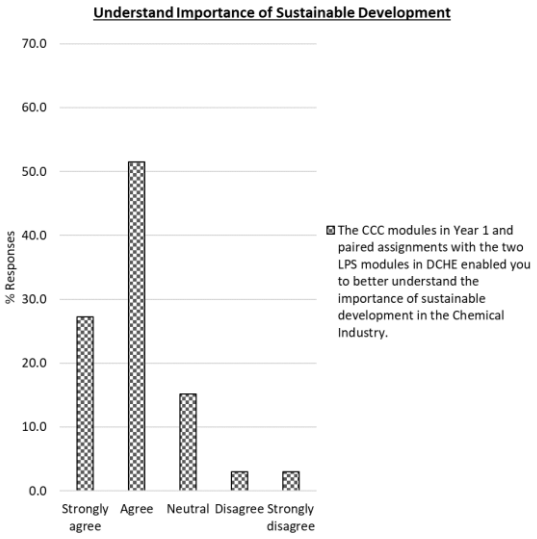


Figure 2. Understand Importance of Sustainable Development

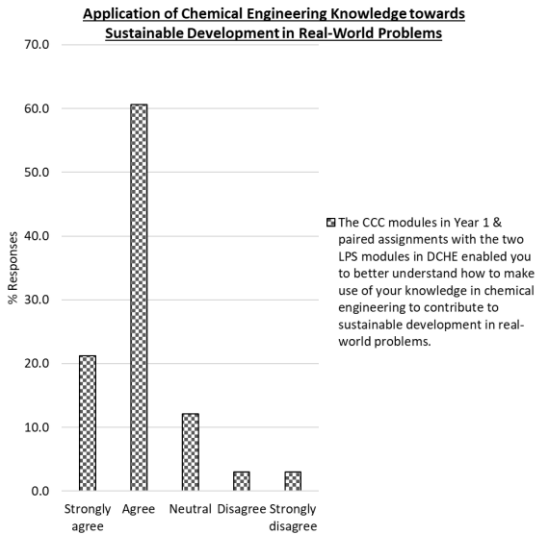


Figure 3. Ability to Apply Chemical Engineering Knowledge towards Sustainable Development in Real-World Problems

From the survey, more than 75% of students agree or strongly agree that the CCC modules in Year 1 and paired assignments with the LPS modules in DCHE enabled them to better understand importance of sustainable development in Chemical Industry (78.8%; Figure 2) and allowed them to better use knowledge in chemical engineering to contribute towards sustainable development in real-world problems (81.1%; Figure 3).

When students were asked specifically whether the assignments crafted for the paired modules enabled them to apply the skills learnt in CCC modules to LPS modules, most agree or strongly agree that they were able to apply skills such as data cleansing and analysis (72.8%), teamwork (78.8%) and communication (78.8%) to assignment scenarios contextualised to their core discipline of study (Figure 4). More than 72% of students agree or strongly agree that they were confident in using these skills in the next year of study (Figure 5).

In the open-ended survey question, students were asked to explain the key challenges faced when they had to apply the skills learnt in CCC modules to the LPS modules in general. A quarter of students mentioned that that they found it hard to link the CCC modules and LPS modules. One student elaborated that "*Sometimes I do not see the link between the two modules and sometimes I may not know when to apply these knowledge learnt in CCC modules to the LPS modules*".

These results suggests that the pairing of the CCC (*Data Fluency*, *Collaboration in the Digital Age* and *Digital Communication for Impact*) with DCHE (*LPS1* and *LPS2*) modules and assignment designs were appropriate and enabled students to see the link and apply the skills learnt from a generic module to their core domain modules when given specific assignments.

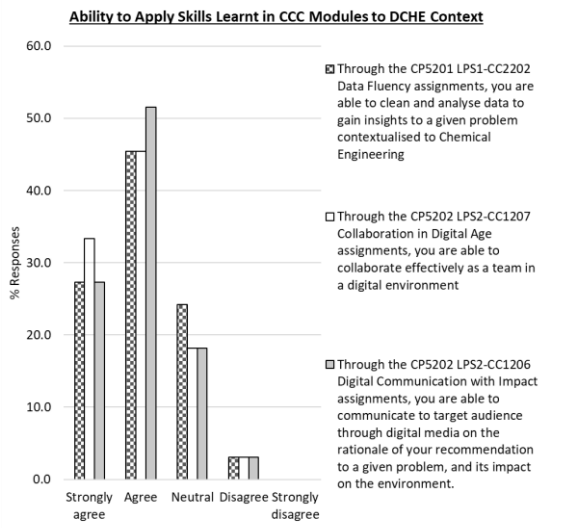


Figure 4. Ability to Apply Skills Learnt in CCC Modules to DCHE Context

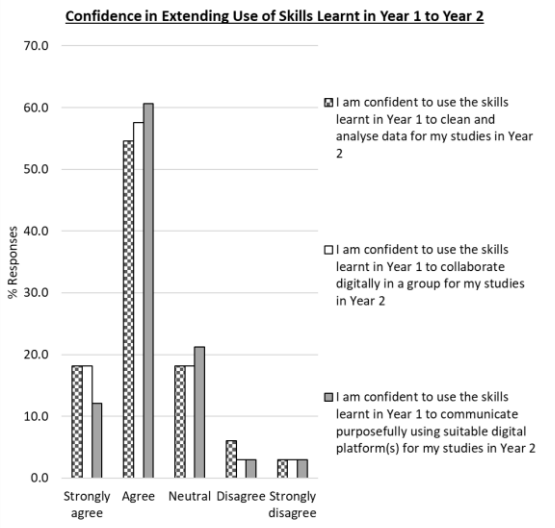


Figure 5. Confidence in Extending Use of Skills Learnt in Year 1 to Year 2

FUTURE AREAS OF IMPROVEMENT

The work done reported in this paper is based on the first run of CCC in DCHE. It provided the lecturers involved in the teaching of *LPS1* and *LPS2* much valuable experience in understanding the requirements of CCC. In this section, several ideas to improve the pairing between CCC modules and DCHE core modules are outlined.

Firstly, for *LPS1*, the current assignment as shown in Table 2 can be modified with one that aligns better with the DCHE curriculum integration effort, more specifically to deepen students' skills in creating better data visualisation using the skills developed in *Data Fluency*. With that in mind, an activity was introduced where students created various charts explaining the relationship how certain process variables (such as temperature, pressure or composition) will affect mixture properties (such as density, specific heat capacity, viscosity, boiling points, etc). These are big data of interest in both chemical processing and product design. To supplement this learning activity, a scenario could be crafted that centers around process and/or equipment design and/or selection when seawater is used for cooling in a chemical plant. This will tie in well with the assignment in *LPS2* which already focused on using seawater in chemical processing industry as mentioned in Table 3.

Secondly, for *LPS2*, students' skills in data visualisation can be further strengthen by tapping onto an existing laboratory experiment on mixing and leaching. Besides learning about key principles in chemical engineering, students also learnt about design of experiments and importance of collecting good data; namely in terms of data validity and reliability. Students can learn to collaborate in collecting data for 8 experimental designs where each student team will investigate 2 different experimental designs. Each team will then share the finding with other teams where eventually all teams will have all the necessary data to analyse, generate discussion and create impactful presentation using the skills gained from *Digital Communication for Impact*.

Thirdly, from Figure 1, in DCHE Year 1, there are 2 other standalone CCC modules; namely *Thinking Critically about the UN SDGs* in Semester 1 and *Artificial Intelligence and its Impact* in Semester 2. As noted in Table 1, core domain module such as *Introduction to Chemical Engineering* can be "unofficially paired" with *Thinking Critically about the UN SDGs*. This will further enhance the DCHE curriculum integration to explicitly make the connection between modules. Another "unofficially" pairing can be done in Semester 2 is with *Artificial Intelligence and its Impact*, contextualised in terms of application of artificial intelligence in water management to align with the assignment in *LPS2* described earlier.

Lastly, the skills developed in *LPS1* and *LPS2* can be enhanced in the context of chemical process plant operation when the students move on to Year 2 where they will complete 2 more skills-based core modules (not shown in Figure 1). Likewise, how skills learnt in *Data Fluency*, *Digital Communication for Impact*, and *Collaboration in the Digital Age* can be further enhanced in Year 2 modules.

The DCHE Course Management Team will conduct a review to map relevant UN SDGs to domain core modules. This will further enhance the integration of CCC skills in the domain core modules is through the use of relevant examples. This learning shall be made explicit to students so that they purposefully apply the knowledge on UN SDGs to the chemical engineering context. The terminal objective is to enable students to better understand the importance of sustainable development in the chemical industry and allow them to use their knowledge in chemical engineering to contribute to sustainable development in a real-world context.

CONCLUSION

The Course Management Team adopted the approach of using the 12 core CDIO Standards to carry out a standard-by-standard evaluation of the extent of sustainable development coverage in the existing DCHE curriculum. This approach is found to be constructive because it guides the evaluation process in a structured and systematic manner.

The findings from DCHE students of their first year experiences provide positive indication that the Course Management Team's decision of pairing CCC modules with the diploma's domain core modules as shown in Figure 1 enable students to see the connection between the skills learnt and students could apply these skills in different context. At the same time, students developed confidence to extend the use of these skills learnt in first year to second year and beyond.

In conclusion, our study has shown that the assignment pairing when executed in a purposeful manner enabled students to understand how and when to use the appropriate skills and apply them at various stages of the course.

FINANCIAL SUPPORT ACKNOWLEDGEMENTS

The authors received no financial support for this work.

REFERENCES

Barth, M., Godemann, J., Rieckmann, M. & Stoltenberg, U. (2007). Developing Key Competencies for Sustainable Development in Higher Education, *International Journal of Sustainability in Higher Education*, Vol. 8 No. 4, pp.416-430.

Cheah, S.M., Lim, L.Y. & Chao, Y.C. (2022). CDIO for Education for Sustainable Development using Common Core Curriculum, *Proceedings of the 18th International CDIO Conference,* June 13-15; Reykjavik University, Reykjavik, Iceland.

Cheah, S.M. (2021). Sustainable Development in Chemical Engineering Curriculum: Review and Moving Ahead, *Proceedings of the 17th International CDIO Conference,* June 21-23 (online); Bangkok, Thailand.

Cheah, S.M. (2019). Teaching Students Self-Directed Learning to Support Education for Sustainable Development, *Proceedings of the* 13th *International Symposium on Advances in Technology Education* (ISATE), September 17-20; Tokuyama, Japan.

Cheah, S.M. & Yang, K. (2018). CDIO Framework and SkillsFuture: Redesign of Chemical Engineering Curriculum after 10 Years of Implementing CDIO, *Proceedings of the 14th International CDIO Conference*, June 28-July 2; Kanazawa, Japan.

Cheah, S.M. (2014). CDIO as Curriculum Model for Education for Sustainable Development, *Proceedings of the* 10th International CDIO Conference, June 15-19; Barcelona, Spain.

Cheah, S.M. & Yang, K. (2018). CDIO Framework and SkillsFuture: Redesign of Chemical Engineering Curriculum after 10 Years of Implementing CDIO, *Proceedings of the 14th International CDIO Conference*, June 28 – July 2; Kanazawa, Japan.

Cheah, S.M., Yang, K. & Sale, D. (2012). Pedagogical Approach to Integrate Sustainable Development into Engineering Curriculum, *Proceedings of the* 8th *International CDIO Conference*, July 1-5; Brisbane, Australia.

Crawley, E.F., Malmqvist, J., Ostlund, S. & Brodeur, D.R. (2007). *Rethinking Engineering Education – The CDIO Approach*, Springer: Science+Business Media LLC.

EDB (2021). *Sustainable Jurong Island*, The Singapore Economic Developmetn Board.

Ericsson, K. (2008). Deliberate Practice and Acquisition of Expert Performance: A General Overview, *Academic Emergency Medicine*, Vol.15(11), pp.988-994.

IChemE (2016). *Chemical Engineering Matters*, 3rd Ed., Institution of Chemical Engineers, UK.

Kioupi, V. & Voulvoulis, N. (2019). Education for Sustainable Development: A Systemic Framework for Connecting the SDGs to Educational Outcomes, *Sustainability*, 11, 6104; doi:10.3390/su11216104.

Lazano, R., Merrill, M.Y., Sammalisto, K., Ceulemans, K. & Lazano, F.J. (2017). Connecting Competences and Pedagogical Approaches for Sustainable Development in Higher Education: A Literature Review and Framework Proposal, *Sustainability*, 9, 1889; doi:10.3390/su9101889

Mezirow, J. (2003). Transformative Learning as a Discourse, *Journal of Transformative Education*, Vol.1, No.1, pp.58-63.

Ng, H.T. & Cheah, S.M. (2012). Chemical Product Engineering using CDIO Enhanced with Design Thinking, *Proceedings of the* 8th *International CDIO Conference*, July 1-5; Brisbane, Australia.

Rosen, A., Edström, K., Grøm, A., Gumaelius, L., Hussmann, P., Högfeldt, A., Karvinen, M., Keskinen, M., Wedel, M., Lundqvist, U., Lyng, R., Malmqvist, J., Nygaard, M., Vigild, M. & Thomas. A. (2019). Mapping the CDIO Syllabus to the UNESCO Key Competencies for Sustainability. *Proceedings of the 15th International CDIO Conference*, June 25-27; Aarhus, Denmark.

Scarff-Seatter, C. & Ceulemans, K. (2017). Teaching Sustainability in Higher Education: Pedagogical Styles that Make a Difference, *Canadian Journal of Higher Education*, Vol.47, No.2, pp.47-70.

SP (2021). Singapore Polytechnic Common Core Curriculum, accessed on February 14, 2023 from: https://www.sp.edu.sg/sp/education/common-core-curriculum

Sterling, S. (2011). Transformative Learning and Sustainability: Sketching the Conceptual Ground, *Learning and Teaching in Higher Education*, Vol.5; pp.17-33

Yang, K. & Cheah, S.M. (2014). Chemical Product Design as Foundation for Education as Sustainable Development, *Proceedings of the 10th International CDIO Conference*, June 15-19; Barcelona, Spain.

BIOGRAPHICAL INFORMATION

Ai Ye OH is one of the members in the Course Management Team for the Diploma in Chemical Engineering, School of Chemical and Life Sciences, Singapore Polytechnic. She has a keen interest in student development and pastoral care.

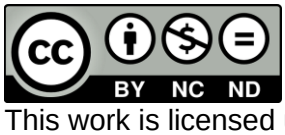
Yunyi WONG is a Teaching and Learning Mentor in the School of Chemical and Life Sciences, Singapore Polytechnic. Her current academic interests include integrated learning and learning analytics.

Katerina YANG is the Course Chair for the Diploma in Chemical Engineering, School of Chemical and Life Sciences, Singapore Polytechnic. She has more than 10 years of experience of education development from SP. She leads the curriculum review for the diploma program to adopt the spiral curriculum model.

Sin-Moh CHEAH is the Lead Specialist in Teaching & Learning in the Department of Educational Development, Singapore Polytechnic. His academic interests include curriculum revamp, academic coaching and mentoring, and using ICT in education.

Corresponding author

Katerina Yang
Singapore Polytechnic
School of Chemical & Life Sciences
500 Dover Road, Singapore 139651
katerina_yang@sp.edu.sg



This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.