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.

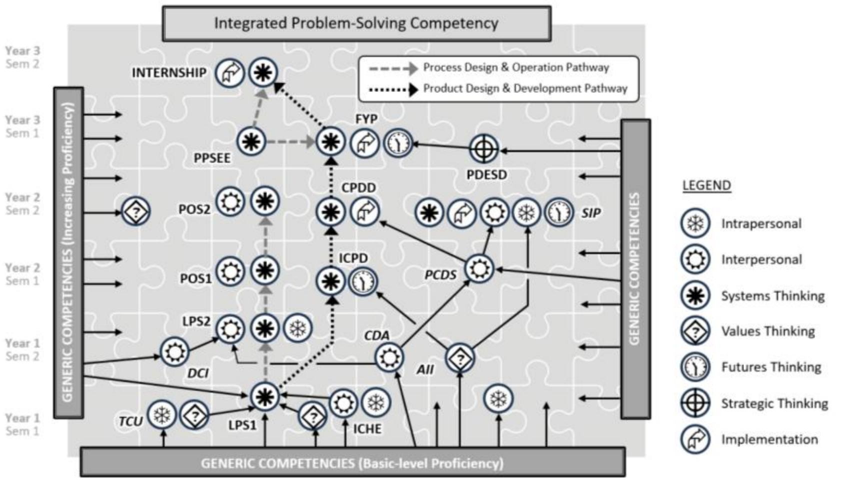
From the survey, we also identified which modules can provide the best contexts for integrating the 7 key competencies for sustainability required to develop the integrated problem-solving competency using the SP approach to develop students' sustainability mindset (Cheah et al, 2025). These are then 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.



Module Acronym
(CCC modules in Italic):

TCU: Thinking Critically about UNSDGs, *PCDS*: Persuasive Communication with Data Story-Telling, *DF*: Data Fluency, *DCI*: Digital Communication with Impact, *CDA*: Collaboration in the Digital Age, *SIP*: Sustainable Innovation Project, ICHE: Introduction to Chemical Engineering, LPS: Laboratory & Process Skills, POS: Process Operation Skills, ICPD: Introduction to Chemical Product Design, CPDD: Chemical Product Design & Development, FYP: Final Year Project, PDESD: Plant Design, Economics & Sustainable Development, PPSEE: Process Plant Safety & Engineering Ethics

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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BIOGRAPHICAL INFORMATION

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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