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.

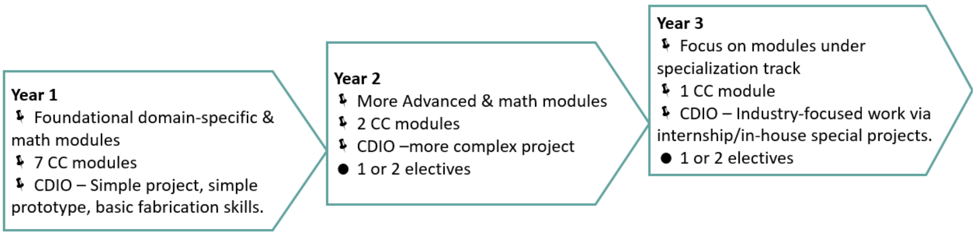

Figure 1. How domain-related skills, core competencies and CDIO skills are progressively built across 3 Years Diplomas in SEEE.

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).

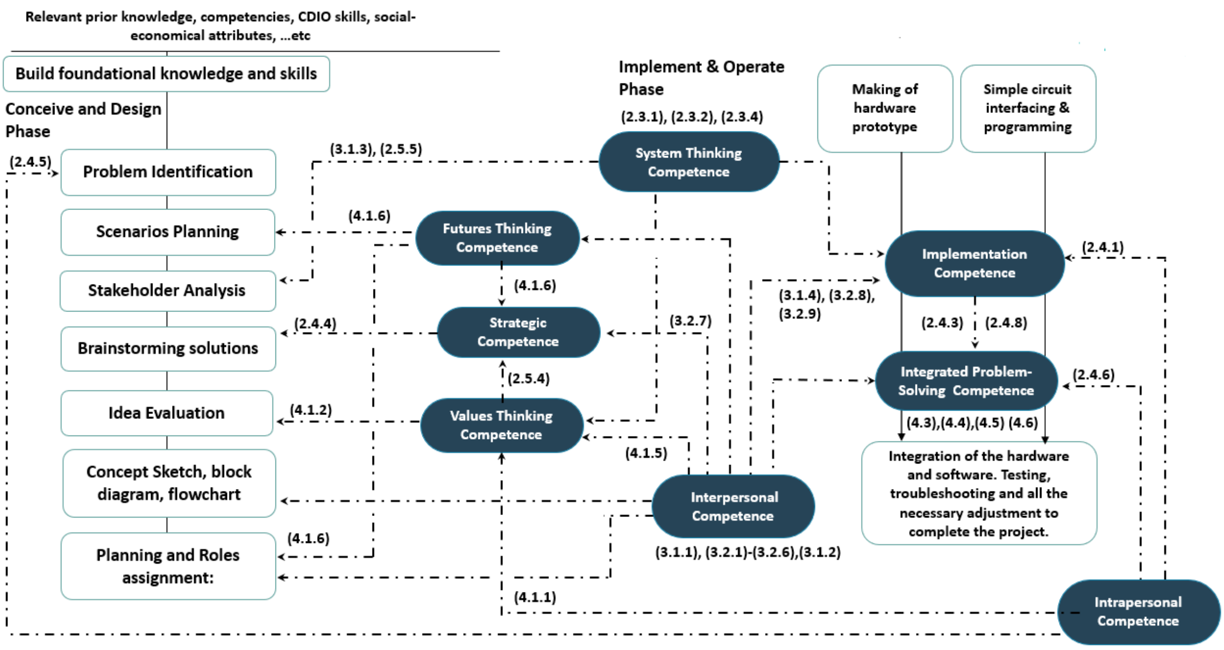

Figure 2. Integrating CDIO Phases with Sustainability Key Competencies in a typical project-based module: A case study of a project in MAPP.

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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