SCAFFOLDING LEARNING TO FOSTER STUDENTS' SUSTAINABILITY COMPETENCIES AND ATTITUDES THROUGH PROJECTS

Dr Chia Chew Lin, Dr Lim Joo Ghee and Dr Tan Kwee Teck
School of Electrical and Electronic Engineering, Singapore Polytechnic

Toh Ser Khoon
Department of Industry & Partnerships

ABSTRACT

Engineering plays a key role to ensure Sustainable Development (SD) in the process of solving complex problems. The paper first presents the new enhanced integrated curriculum in the School of Electrical and Electronics Engineering (SEEE) and the current work done to integrate sustainability learning for SEEE students. With the need to increase sustainability learning within the SEEE, all the second year SEEE students who need to take the core project-based module: Microcontroller Applications (MAPP) has been identified to incorporate United Nation (UN) Sustainable Development Goals (SDGs) in their project. The paper then presented how the prior knowledge, experiences, and key relevant sustainability competencies are fostered via scaffolding learning which is integrated in this new curriculum when the students are working on their MAPP Project. This is aligned with CDIO standard 7 and the newly updated Optional CDIO standard 1 that aims to address SD.

At the end of the Conceive and Design phase of the MAPP Project, a survey was conducted for all the 2nd year students enrolled in the MAPP module in AY2022/2023 Semester 2. A total of 148 (61%) of 243 students responded to the survey. Combined with the findings from the focus group discussion and casual conversation with 5 teaching staff, the majority of the students see the value of working as a team and are able to relate what they have learned in relevant modules as some level of key competencies must be attained in order for them to complete the project. Finally, the paper shares the limitations of the study and possible future improvement plans.

KEYWORDS

Sustainable Development, UN SDGs, Common Core, Sustainability Competencies, CDIO Optional Standard 1, CDIO Core Standards: 3, 5 and 8

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Computer Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called “courses”.

AN ENHANCED INTEGRATED CURRICULUM IN SEEE

In the recent years, building priority competencies in high demand growth areas has been the highlight of Singapore Polytechnic (SP). This is to ensure that our graduates are capable and

able to tap into new opportunities such as the growing green economy as well as to support the Singapore Green Plan 2030 (SGP30) which is a whole-of-nation movement plan to advance the nation's agenda on Sustainable Development (SD).

Over the years, the School of Electrical and Electronics Engineering (SEEE) has enhanced its integrated curriculum to develop students' competencies across different disciplines as we need a new generation of graduates who can work collaboratively across disciplines to find effective, integrated SD solutions (Chia, Lee, & Hongli, 2022). Figure 1 illustrates the recently revamped curriculum structure. The inner circle refers to the type of modules the SEEE students will take throughout their 3 years diploma course and the outer circle is an expansion of the domain modules which comprises of the knowledge-based and project-based modules. Relevant modules that are incorporated with CDIO approach are indicated as " * ".

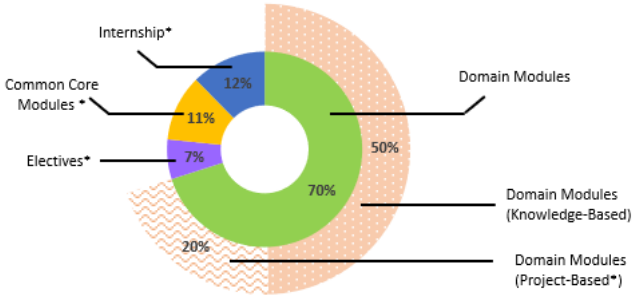

Figure 1. The New Integrated SEEE curriculum. Note: % may vary slightly for different diplomas offered under SEEE. * denotes with CDIO elements.

Survey

In this new curriculum, all SEEE students must take the Common Core (CC) modules and core domain modules in their discipline. The CC modules comprise of in-demand emerging critical human and digital skills across industries to help prepare students to be globally-minded problem solvers in a disruptive world that is ever-changing, using the United Nations (UN) Sustainable Development Goals (SDGs) as the context. More information about the SP's Common Core Curriculum can be found in (Cheah, L.Y., & Chao, 2022) work. The core domain modules comprise of modules to equip students with the foundational knowledge and skills in the industry-relevant fields offered under the various diploma courses. Besides taking the compulsory core modules, SEEE students get to enjoy the flexibility in charting their own learning path when it comes to the selection of their electives. As a continued effort to support the SGP30, more specialized electives such as Solar Photovoltaics System Design, Autonomous Electric Vehicle Design, Integrated Building Energy Management System and related green-modules are currently offered to prepare our graduates to thrive in the identified green sectors. The students can thus take the opportunity to broaden or deepen the skills related to SD with these selections. In the final year, all SEEE students will need to go through a compulsory gradable Internship Programme. Via this programme, there are plenty of opportunities for students to work for an extended period on real-world projects related to SD. For example, students get to work with industry partners for 22 weeks to build a solar greenhouse with an Internet of Things (IoT) monitoring system that can adjust the optimum level of light energy required for the different stages of plant growth. As presented, the new curriculum and all the changes have created more sustainability learning opportunities which are made as authentic and engaging to the students as possible. To continue strengthening sustainability learning relevant to SEEE's discipline, the Microcontroller Applications (MAPP) module, a project-based core module that all the 2nd year students from Diploma in Computer Engineering, Diploma in Electrical Electronics, and Diploma in Engineering Business must take, is selected to include UN SDGs as the project goals.

In the following section, we will look how learning is scaffolded in this new enhanced curriculum to provide opportunities for our students to foster the following key relevant sustainability competencies with their definitions given as follows (UNESCO, 2017), while they are working on the MAPP project.

Systems thinking competency: the ability to recognize and understand relationships, to analyse complex systems, to perceive the ways in which systems are embedded within different domains and different scales, and to deal with uncertainty.

Anticipatory competency: the ability to understand and evaluate multiple futures – possible, probable and desirable – and to create one's own visions for the future, to apply the precautionary principle, to assess the consequences of actions, and to deal with risks and changes.

Critical thinking competency: the ability to question norms, practices and opinions; reflect on own one's values, perceptions and actions; and take a position in the sustainability discourse.

Collaboration competency: the ability to learn from others; understand and respect the needs, perspectives and actions of others (empathy); understand, relate to and be sensitive to others (empathic leadership), deal with conflicts in a group; and facilitate collaborative and participatory.

Integrated problem-solving competency: the overarching ability to apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive and equitable solution that promote sustainable development – integrating the above-mentioned competencies.

SCAFFOLDING LEARNING STRATEGIES IN MAPP PROJECT

The MAPP module is a project-based module designed with a strong focus on active experiential learning (Felder, 2009), aiming to stimulate interest in and strengthen motivation in students in the field of engineering through real-world microcontroller applications. In this module, the students will first learn about the theory and applications via online lectures and practical lessons in the laboratory, required for a microcontroller-based application. The students will also need to take mini-assessments to ensure that they learned the materials. This is to ensure the students are equipped with the foundational knowledge and skills before the start of their project. As part of the requirements to fulfill the module, the students will work in teams of three to four students to complete a project using the CDIO approach (Crawley, Malmqvist, Ostlund, & Brodeur, 2007). Each team is required to use a microcontroller and available electronic devices and components provided in the laboratory to complete their project within the given schedule. Figure 2. shows the students' activities at the different CDIO stages of the MAPP project, split into term 1 and term 2.

For students to develop a good MAPP project, it requires a complex mix of key knowledge, skills, and attitudes in order to create a sustainable and innovative prototype solution centered around a microcontroller that contributes to their selected UN SDGs. To help students to develop the ability to integrate these various skills effectively, there is a need, firstly, to provide a fair degree of application knowledge to develop the essential key component skills. With proper scaffolding, we can help students to form knowledge structures, "that are accurately and meaningfully organized and help students to better able to retrieve and apply their knowledge effectively." (Ambrose, Bridges, Lovett, & Norman, 2010, pp. 4-5).

As seen in Figure 2, before the students take the MAPP module, they would have been equipped with the foundational domain knowledge, such as basic laws and theorems which

govern the operation of electrical circuity, basic C programming language, and so on in their first-year studies. They also have plenty of opportunities to develop their ***collaboration competency*** and behavioural attributes such as social skills as the school adopts the use of the peer assessment as a tool to enhance their teamwork competency whenever they need to work as team since their first year.

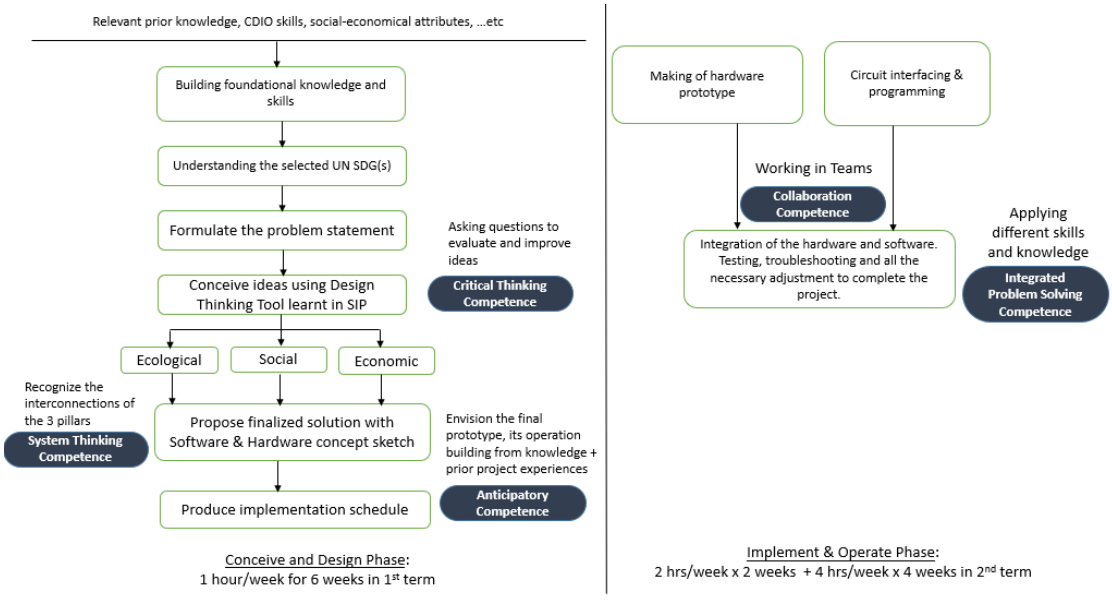

Figure 2. Scaffolding of the key competencies at various CDIO stages when students work on the MAPP project.

The students will also be familiar with the CDIO approach as they worked on a project in the module *Introduction to Engineering* with guided CDIO elements during their Year 1, 1st semester. The module focuses more on the "implement" and "operate" phases of the CDIO when the students are expected to work in pairs to apply what they have learned from the relevant core technical module to implement, build and test a working project based on a given set of specifications. The "implement" and "operate" skills are further deepened as the students acquire the basic "Fab Lab" skills, learning about 2D drawings, isometrics, and orthogonal projections, 3D-Design using Autodesk software for 3D printings, and Laser cutting assignments covered in the module "*Computer-Aided Design & Drafting*". This happened in their first year, either in their 1st or 2nd semester.

To integrate the sustainability concept into the project, each team is expected to select their challenge from one or more of the 17 UN SDGs as shown in Figure 3b. The theme is meant to be an open-ended problem, so the team is given the autonomy to select a shared goal they feel more personally connected to. This can help to enhance students' motivation as they are likely to see themselves as initiators of their own activities and become more self-propelled to act to realise their own ideas (Ryan, 1980). The students can also easily find the necessary information on the UN website which helps them to understand the complexities and challenges related to their selected UN SDG(s) and formulate their problem statement.

As the students progress to their second year, they get the chance to work with a multidisciplinary team that makes up of students from different schools in the module: *Sustainability Innovation Project* (SIP). In this module, students will learn to use and apply the SP Design Thinking (DT) framework (Ping, Chow, & Teoh, 2011) and tools to tackle local

societal issues. To widen students' perspectives, the given problem statements tend to encapsulate a multi-disciplinary issue. When the students get to interact with someone of a different background, they will get to learn something new. This will help to widen the students' perspective and help to develop a multi-disciplinary mindset. Thus, when the students work towards conceiving their ideas for their MAPP project, they are deepening their CDIO skills as they get to apply the SP DT tools they have just learned either in the same semester or one semester before.

After formulating their challenge, the students will apply qualitative techniques of information gathering via interviews and observation using the DT tools provided in the context. After this, the team will then generate as many ideas as possible and evaluate them based on their impact and feasibility level. The impact is assessed based on the level and scale of benefits their proposed solution can contribute towards their selected UN SDG(s). This activity helps to strengthen the student's ***critical thinking competency*** as they question the norms and practices to improve their ideas.

(a) (b)

Figure 3. (a) The 3 pillars of Sustainability (b) How the 17 UN SDGs were clustered into the three pillars of sustainability

As the SD is built on top of the 3 pillars of sustainability (Brundtland, 1987), namely the environment, society, and the economy, with its interaction shown in Figure 3a**,** each team is also expected to assess the overall sustainability of their proposed solution using the 3 pillars. This extra requirement is added to introduce the students to *system thinking*, allowing them to explore the interactions between the 3 pillars. They also learn that true sustainability is only achieved when the environmental protection, social equity, and economic profitability intersect without one area taking over any of the others.

As each team is working towards one or more of the UN SDGs, each team will naturally aim for a solution that will already address at least one of the 3 pillars of sustainability, as seen in Figure 3b. To guide the students to develop system thinking competency, an extra section of the assessment rubrics and case studies examples were provided to the students. In the provided examples, students were encouraged to use an inquiry approach to research and gather insights that take into account the other two pillars of sustainability by asking relevant questions, such as "Will the developed product increase or reduce the use of energy?". This will help the students to develop their ***system thinking competency*** and encourage students to develop appropriate technical solutions that contribute to SD.

Using the prior knowledge and practical skills they picked up in the microcontroller practical sessions, each team should be able to assess the technical viability of their proposed idea without much trouble. After the evaluation, the team will then pick on the one with the high impact and high feasibility idea to work on. They will again consider the overall sustainability of their conceived idea against the 3 pillars to see if they can further enhance their idea. If the

team is not able to conceive an idea that intersects with the 3 pillars, the team simply needs to acknowledge that it is never a simple task to achieve true sustainable solutions in all situations. Instead, what they can do is apply critical thinking to balance and manage the trade-offs. (de Magalhães, Danilevicz, & Palazzo, 2019).

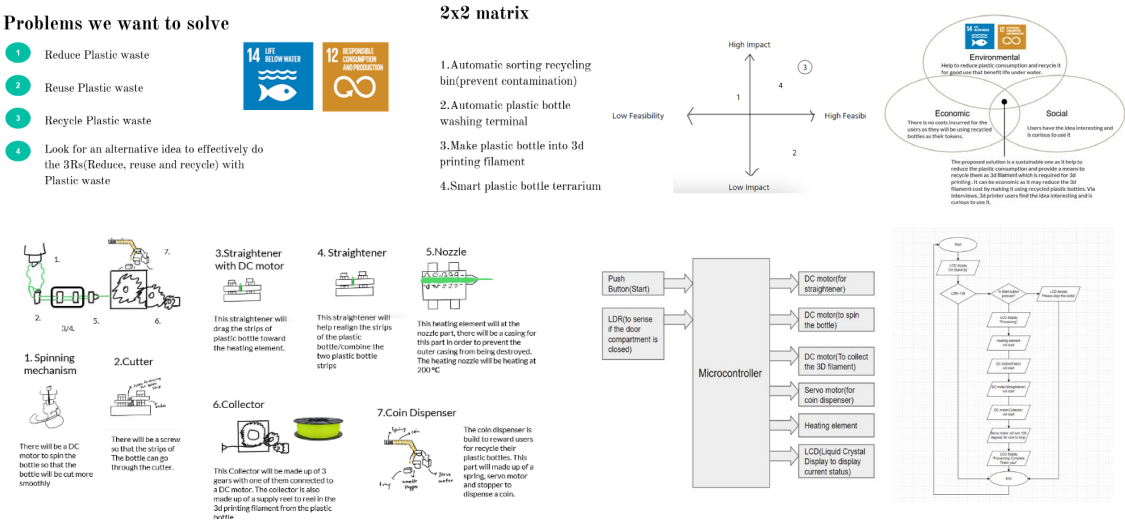

Figure 4. An example of a group's work showcasing the key stages at their Conceive and Design phase of the MAPP Project

Once the idea is finalized, each team will begin to construct a concept sketch, block diagram, flowchart for the hardware and software implementation. During this phase, the lecturer will often provide feedback so that students can better visualize the process of creating their solution, forecast the possible issues with the operation, and make changes to deal with it, thereby developing their ***anticipatory competency***. Finally, each team will construct an implementation schedule with key milestones to manage their project. Figure 4 shows an example of the key stages of a team at the Conceive and Design phase of the MAPP Project.

When it comes to the 2nd term, the students will focus on the "implement" and "operate" phases of the project. During these phases, the students will have to tap into what they have learned in the MAPP and other relevant modules, or even learn new things on their own to build the project. With continuous feedback from the lecturer and iterations, some teams may need to do some modifications or changes to the original ideas for successful completion. Going through this phase may not be easy for the students but it can help students to deepen the necessary key competencies and pick up various implicit valuable skills. This includes deepening their technical skills such as programming, troubleshooting skills and strengthening attitudes such as becoming more resilient.

Finally, when the students work together to apply the necessary skills and knowledge to complete the MAPP project, they are developing ***integrated problem-solving competence***. Figure 2 summarized how the students develop the key competencies to perform the complex tasks/activities when working on the MAPP project.

DISCUSSION

At the end of the Conceive and Design phase of the MAPP Project, a survey was conducted for all the 2nd year students enrolled in the MAPP module in AY2022/2023 Semester 2. A total of 148 (61%) of 243 students responded to the survey conducted. A summary of the survey results grouped into different subscales is shown in Table 2.

Table 2. Results of the survey grouped according to the subscale.

Sub scale	SD = Strongly Disagree, D = Disagree, N = Neutral, A = Agree, SA = Strongly Agree Results in %	SD	D	N	A	SA
A	As a result of the MAPP Project, I develop a ***better*** understanding of UN SDG(s) I am working towards in the real world.	4	5	18	51	22
A	I am able to understand the current situation of the selected UN SDG(s) that I am working towards it.	1	4	16	57	22
V	Understanding more about UN SDGs help me to see things in a wider perspective.	2	5	21	54	18
V	I want to work on projects that contribute towards the UN SDG(s).	2	4	34	43	17
V	I find the ability to assess the social, environment and economical elements of the project is a useful skill.	1	1	12	65	21
V	Working in a team to solve a problem is a very valuable to me.	1	1	9	58	32
ST	As a result of the MAPP Project, I can recognize the interdependency among the social, environment and economical elements of my MAPP project.	3	0	15	64	19
ST	I understand the benefits as well as the possible impact (e.g. environment costs) associated with my conceived idea in MAPP project.	4	1	9	70	17
CT	When conceiving ideas, I am able to question the norms, practices and opinions.	2	1	23	52	21
A	I am able to visualize the final product and forecast possible issues with the operation of the product and make changes to deal with it.	1	1	20	52	26
CC	I am able to learn from my team members.	1	0	12	50	37
CC	I am able to relate to and be sensitive to others (empathic leadership) and deal with conflicts (if any) in a group.	1	0	16	61	22
ISP	I am able to connect and see the relevance of the CDIO concept and skills I have learnt in other modules e.g. Design Thinking in SIP.	1	1	19	58	21
ISP	I am able to connect and see the relevance of the concepts taught in other technical modules I take e.g. PEEE.	1	0	16	56	27
Subscales: Awareness (A), Attitudes/Values (V) and the 6 identified Competencies namely System Thinking (S), Critical Thinking (CT), Anticipatory (A), Collaboration (CC) and Integrated Problem-Solving Competency (IPS)						

From the survey, about 70% of the respondents agree or strongly agree with the first two items related to enhanced awareness. Only about 60% of the students agree or strongly agree that they want to work on a project that contributes towards the UN SDGs. More than 75% of the students agree or strongly agree with the rest of the statements relating to other values/attitudes and their self-perceived competencies. However, the results should be interpreted in relation to the limitations of the study. One of the limitations is that further research is needed to assess the validity of the survey items as only the 4 items relating to students' perceived value and attitudes were adapted from (Lanziner & & Strong, 2018)'s work with face validity and reliability. Another limitation is that the self-reported survey can be prone to social desirability bias. Thus, we need to combine the findings obtained from the written responses, focus group interviews, and the teaching staff.

In addition to the survey, the written responses and the qualitative feedback from the group discussion conducted for 7 students were examined. On the whole, the responses from the students have an overall positive sentiment with the selected comments from students' responses grouped with similar meanings shown in Table 3. Irrelevant comments such as "N\A' were omitted and not counted.

Table 3. Selected representative students' comments grouped accordingly to their meanings

No. of response	*Selected representative comments on* "What did you get the most out of working on your MAPP Project so far?"
26	*"Understand how to put in class knowledge into real world applications"*
12	*"Working with my group mates has taught me a lot and helped me to grow in the multiple skills that i've picked up like coding which i felt was what i got the most out of this project."*
5	*"Project planning and project management"*
5	*"Understanding the importance of sustainability"*
No. Of response	*Selected representative comments on* "What did you get the most out of working on your MAPP Project?*"*
12	*"More sensor variety to be given so that we would not need to purchase sensors ourselves."*
9	*"other helpful links / videos / notes that can aid us in our learning for exams and for better understanding MAPP"*
4	*"more time to do the practical part of project."*
3	*"Not just fixating on the topic sustainability"*
2	*"simpler project, less quizzes, easier MST"*
2	*"lecturer need to help us more"*

Specifically, all the 7 students who participated in the interview were all able to see the value of working as a team (90% of the respondents agree/strongly agree on this as well) as they find the project to be pretty huge and they need to split the work. All 7 students were also able to cite their specific examples on how they see the relevance of other modules applied to MAPP project. For instance, as one student commented:

"I can see how the module IE helps. It is a module is more on doing. It gives us an idea how the project will look like instead on paper."

A total of 5 (out of 12) teaching staff's views were also sought via a one-to-one 20 to 30 minutes long causal conversation over the phone. On the whole, they all felt MAPP is a very useful module as students need to integrate the necessary prior knowledge and skills that they have learned to complete the project. All of them felt that it is purposeful to have UN SDGs as the project goal as compared to the past practice of leaving it to students to do what they wanted to as long as they meet the project requirements. One of them shared that there were past examples where students completed a project and it is difficult for him to see the value and meaning in their project's outcome. However, it remains unknown as to why some students responded that they do not agree to work on projects that contribute to UN SDGs. The staff also have similar comments that only the more motivated students are willing to spend more time and effort to deepen the needed competencies to work towards a solution that is more challenging. On the other end, the weaker and/or less motivated students would usually try to shun away working on the "better solution" if they find it more challenging to work on and would choose an easier solution for themselves. If not, these students may also be likely to contribute less to the team. This may explain the written responses of "*simpler project, less quizzes, easier MST"*. One staff also shared his observations that some students may try to brag that

their proposed solution is truly sustainable without providing much insight as they may perceive being marked down if the solution is not considered to be truly sustainable.

FUTURE WORKS

From the findings, the following are some of a few areas where we can work on:

1) The survey items could be improved with a 7-point Likert-type scale to increase variance in responses as it may be more useful for future comparative analysis.
2) Every student will have different starting point for the different targeted competencies. Thus, a pre and a post self-assessment together with the teaching staff's inputs can be gathered to provide more insights if working on the MAPP project did help students to acquire/strengthen the targeted competencies.
3) Explore the possibility of increasing the variety of hardware sensors and actuators with the course team.
4) A separate study of students' motivation working on a sustainability-theme project may be worthwhile to be carried out since it seems to be a predicator of student involvement and their development of the key competencies.

CONCLUSION

The paper first presented the new enhanced integrated curriculum and the work done to integrate more sustainability learning for SEEE students. The paper then presented how the key component skills such as basic programming, design thinking, fabrication skills were scaffolded via the prior learning activities in this enhance curriculum. To gather an initial insight to see if the students can relate to what they have learnt with the aim to build the 5 key sustainability competencies and the relevant attitudes, an initial survey was conducted. Although there is social-desirability bias in self-report studies, the combined findings agree that majority of the students see connection of what they have previously learnt and the value in working in a team. The staff who were interviewed also agreed that some level of the key competencies must be acquired in order to complete the project. Future work to understand if the competency level has improved after working on the MAPP project was also proposed.

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BIOGRAPHICAL INFORMATION

Chia Chew Lin is the Academic Mentor of the School of Electrical and Electronic Engineering at Singapore Polytechnic. She loves to experiment with new teaching ideas to enhance students' intrinsic motivation in learning. Her current interests and focus is identifying the current learning problem or teaching ineffectiveness and work to improve on it.

Joo Ghee Lim is currently the Director of the School of Electrical & Electronic Engineering (EEE) from Singapore Polytechnic. Joo Ghee believes strongly in pedagogical innovation within the classroom and offering differentiated learning experiences to students to bring about self-directed learners. To that end, he leads the School of EEE in its endeavour to constantly innovate new Teaching & Learning approaches to train engineers for today and tomorrow's industry. Joo Ghee's technical domain interest lies in Internet of Things, Wireless Communications, Networks, 5G and Digital Transformation.

Dr Tan Kwee Teck is currently the Deputy Director (Course Management), School of Electrical & Electronic Engineering, Singapore Polytechnic (SP). Over the 20+ years with SP, Kwee Teck teaches modules in communication systems, computer networking, network security, software programming, Internet of Things, etc. Over the years with SP, Dr Tan has been awarded SP Educator Award (2019) and Excellence in Teaching Awards (2014 and 2004).

Toh Ser Khoon currently holds three positions: Director, School of Industry and Partnerships (INP), Singapore Polytechnic; Managing Director, Singapore Polytechnic International (SPI); and Managing Director, Institute for Financial Literacy (IFL). He has more than 25 years of experience in the public sector, holding various management positions. In whatever positions he helms, he leads by example to build up an innovative culture, bringing about continuous improvements. His approach is always to share innovative practices, systems and processes to build capabilities and to capitalise on collaboration efforts with stakeholders and the industry.

Corresponding author
Dr Chia Chew Lin School of Electrical and Electronics Engineering Singapore Polytechnic 500 Dover Road, Singapore S139651 65-68708244 Chia_chew_lin@sp.edu.sg