PASSION AND CHOICES IN ENGINEERING EDUCATION THROUGH MULTIPLE PATHWAYS

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ABSTRACT

Students with diverse academic abilities, interest and inclination are studying engineering courses. CDIO Standard 2 defines learning outcomes codified in CDIO Syllabus 2.0 (CDIO 2020) to train competent graduate engineers. Effective training requires curriculum that integrates different components defined in CDIO Standards. A linear "one-size-fits-all" approach where all students go through same curriculum throughout entire course of study is likened them travelling on a single-lane in a tunnel with one entrance and exit. Such learning does not meet aspirations of some students. This paper describes how the School of Electrical and Electronic Engineering of Singapore Polytechnic (SEEE) embarked on the design of curriculum with multiple pathways that give students choices to pursue learning that matches their interests and abilities. The innovative curriculum stretches students' limits to learn beyond traditional lecture and tutorial, extends learning outside the confine of laboratory and campus, and raises learning beyond the standard curriculum. Students take modules in their chosen pathway in lieu of standard modules. All pathways have the same objective to nurture competent graduates by the end of the 3-year study. In essence, engineering education is enhanced and students are stretched to their maximum potential to become competent, versatile and self-directed engineers ready for 21st century workforce.

KEYWORDS

Learning Outcome, Multiple Pathways, Passion, Choice, Agile, Collaboration, Experiential, Integrated Learning, CDIO Standards: 1, 2, 3, 6, 7

BACKGROUND

Singapore Polytechnic is a government-funded tertiary institution with 10 academic Schools. SEEE admits full-time students who are from 17 to 20 years old to do a 3-year course in one of the four Diplomas, in Aerospace Electronics, Computer Engineering, Electrical and Electronic Engineering, and Engineering with Business. Our mission is to prepare learners to be life, work and world ready. Our vision is to develop students to be inspired learners who are purposeful, motivated and self-directed ("SP Mission & Vision", 2021).

SEEE's full-time enrolment is around 800 each year and comprises of students with very different abilities and entry qualifications. Majority gain admission with the General Cambridge Examination (GCE) Ordinary Level ('O') Certificate based on "ELR2B2" aggregate score of grades in **E**nglish **L**anguage, two **R**elevant subjects and two **B**est subjects. The subject grade ranges from 1 to 9 with a smaller number better than a larger one. The ELR2B2 score ranges widely from 5 to 26 points for our students. Other qualifications like General Cambridge Examination (GCE) Normal Level ('N') Certificate, and the National Industrial Technical

Certificate (NITEC) and Higher National Industrial Technical Certificate (HNITEC) which are awarded by Singapore's Institute of Technical Education (ITE), as well as foreign qualifications attained by international students are also considered for admission. Such diverse students' abilities call for a curriculum that offers multiple pathways where students could choose a programme that best matches their learning needs.

SP EDUCATION MODEL

The SP Education Model is depicted in Figure 1. Underpinning our education is the curriculum for applied and professional training. SP's course curriculum comprises of three components, namely Domain, Common Core and Choice. Domain consists of modules directly relate to the discipline of study. For example, a domain module in Diploma in Aerospace Electronics is Aircraft Communication & Navigation. Common Core modules are those pertaining to cross-industry and cross-domain human and digital skills and are taken by all SP students from all courses. The Choice space offers students the opportunities to take modules which are aligned to their interest and learning needs. It is for this purpose that the framework of multiple pathways is conceived where each pathway has a unique curriculum specially curated to match the different learners' passions and abilities.

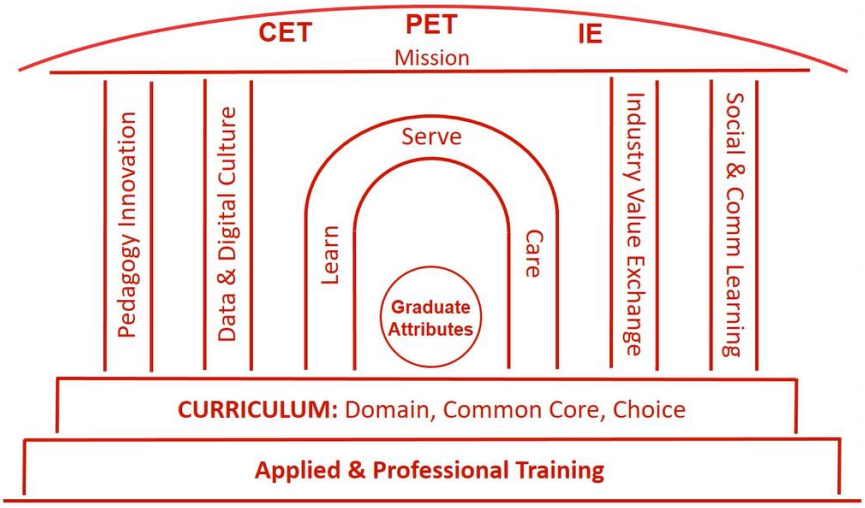


Figure 1. SP Education Model

CURRICULUM DESIGN FOR MULTIPLE PATHWAYS – PROVIDING CHOICES

There are problems in adopting a linear "one-size-fits-all" curriculum where all students in the same course take the same set of modules throughout the 3 years of study. These students have very diverse academic abilities, motivation and aspiration with the high ability ones potentially feel deprived from challenges if they do the standard structured curriculum (Reis and Renzulli, 2010) while academically weak students would find it difficult to cope. There is a need to motivate students to master learning tasks and achieve goals through differentiated and targeted approaches (Tomlinson 2014).

Today's education allows collaboration by different stakeholders to create multiple pathways to deliver learning. A framework to conceive and design curriculum with multiple pathways that enhance experience and meet aspiration of Gen Z students who often seek more personalised

and experiential learning (Schwieger and Ladwig, 2018) is needed. In particular, learning does not only take place in campus, but rather, students could acquire skills and knowledge from a variety of platforms and sites (Marsh 2009). The School has developed an innovative framework called ***ACE*** (which stands for ***A***gile, ***C***ollaborative and ***E***xperiential) for designing multiple pathways. Each pathway is constructed within the Choice space of a specific diploma course. Figure 2 shows the main course curriculum with five available pathways.

Each pathway is curated with ***agility*** in term of course construct and contents. Students in their chosen pathway do not always follow the same sequence or contents taken by the majority of students in the same course. Learning in each pathway is specially conceived and curated to ensure academic rigour is maintained and students' workload is comparable to those doing the standard curriculum. CDIO Standard 2 is applied to align curriculum and learning outcomes with institution's vision and mission, and course's aims. Students are equipped with the required knowledge and skills to be competent engineers by the end of the course regardless of which pathways they are in. Flexibility is key if students are to be given choices of different learning approaches that best meet their learning needs, abilities and passions.

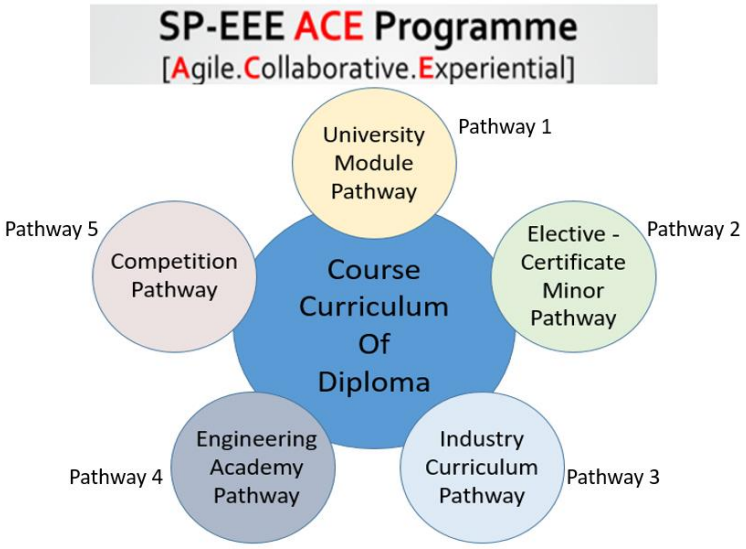


Figure 2. SEEE ACE Framework for Multiple Pathways

Pathways are curated ***collaboratively*** with partners from the industry, universities and relevant organisations that offers learning of engineering skills. Learning is not solely delivered by academic staff as partners' capabilities and resources are tapped to equip students with relevant skills and knowledge contextualised to the platform in which learning takes place.

Finally, unlike in traditional lecture, tutorial and laboratory lessons, students learn and explore new knowledge and skills in highly varied and ***experiential*** environments. Some get to experience university life by reading university-level modules with classmates who are a few years their senior. Others take up year-long attachment to research agencies or organisations to explore emerging technologies such as Robotics, Cybersecurity, and Artificial Intelligence of Things in projects. Others are coached by experts in selected fields of engineering such as Industrial Control, IT Networks or Rapid Transit System to participate in competitions at national and international levels such as the World Skills Competition, which allow talented students to showcase not only their skills but also to develop resilience as they out-wit, out-perform and out-last competitors from countries all around the world.

Students are briefed on the different pathways at the beginning of their courses. Majority are placed in the "normal pathway" where they take modules in the standard structured curriculum. Suitably qualified students could apply to different pathways that interest them and meet their personal goal and aspiration. Selection of students is carried out through a rigorous process.

SEEE aims to develop students to be inspired learners who are equipped with strong competences and imbued with values such as self-directedness, intrinsic motivation, growth mind-set, and versatility. SEEE recognises both the hidden and revealed potentials of the students and its commitment to nurture them is etched in the School's motto which states "Nurturing Curious Minds, Producing Passionate Engineers – From Potential to Fulfilment". This contextualises the training to produce skilful and competent engineering graduates who are capable of conceiving, designing, implementing, and operating complex and sustainable products, processes, systems and services in modern team-based environment emphasized in CDIO Standard 1. Several pathways have been designed and integrated successfully into the curriculum. A fundamental principle is to have a flexible structure that supports integration of knowledge and skills with multi-disciplinary connections (CDIO Standard 3) so as to create meaningful learning experiences for students (CDIO Standard 7) according to their ability and aspiration. Interviews by Ellington (2006) showed high-performing students enjoyed challenges in academic studies. Pekrun (2006) emphasized the importance of balancing these challenges with ability to develop intrinsic motivation of each student. While academically capable students have choices of different pathways, SEEE is mindful of students at the other end of the ability spectrum. Hence, academically weak students are helped through peer tutoring and supplementary class to better manage learning and cope with stresses.

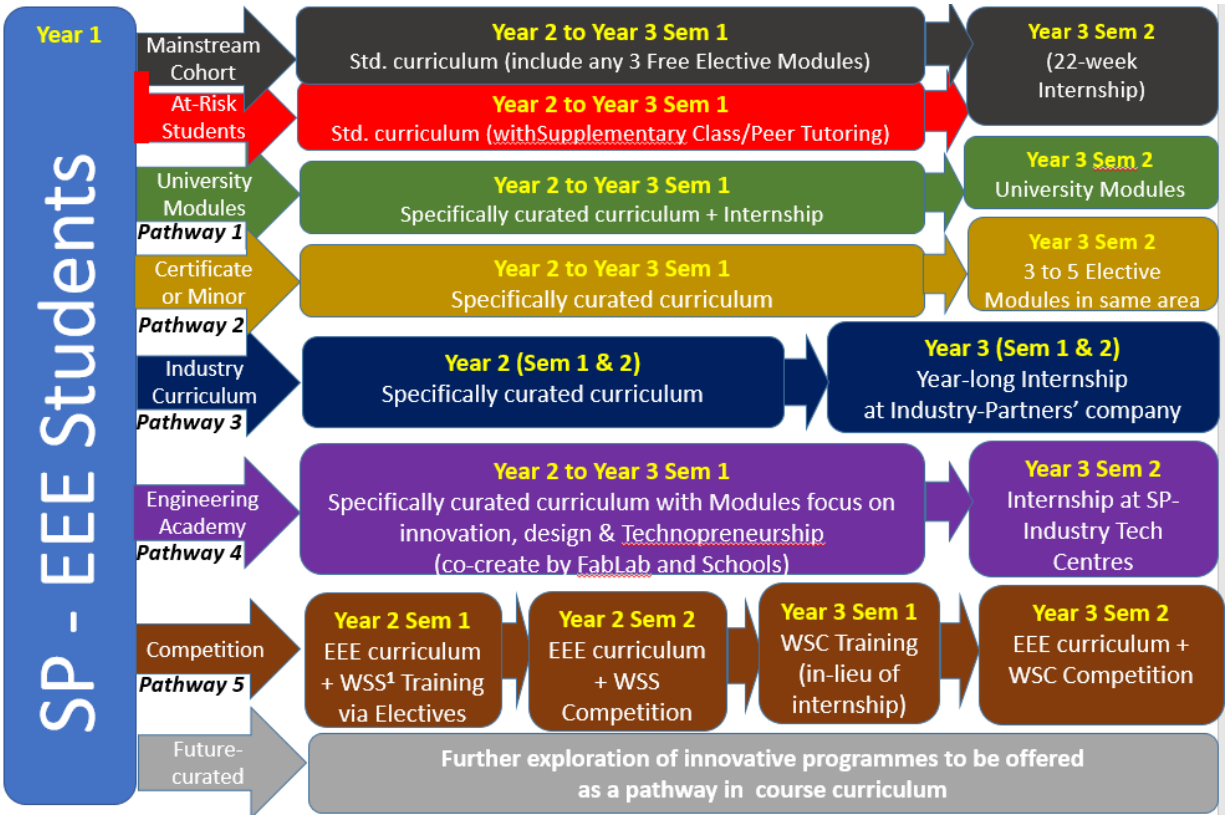


Figure 3. Innovative Design of Multiple Pathways in SEEE Courses

DESIGNING MULTIPLE PATHWAYS

Figure 3 gives a snapshot of students' possible journeys in their 3 years of study leading to a diploma qualification. Students could apply to a pathway subjected to meeting the criteria if its learning design matches their talents and passion.

UNIVERSITY-LEVEL MODULE PATHWAY

Rationale

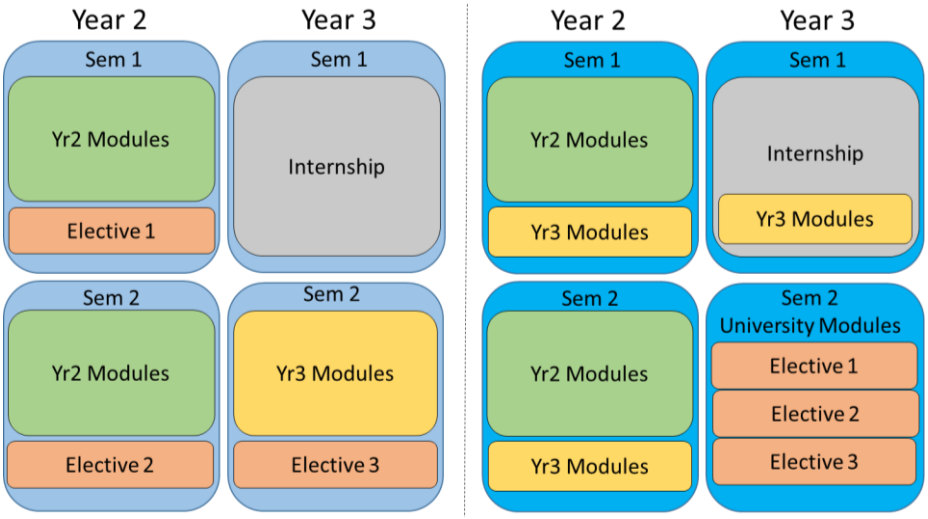
The impetus of this pathway stems from the understanding that many students aspire to further their study to obtain a degree after graduating with a diploma. Each year SEEE attracts a group of highly capable and motivated students who have attained very good GCE O-Level results. Many are "single-pointer" with ELR2B2 score of less than 10 and qualify to study at reputable colleges to take GCE 'A' (Advanced) Level before pursuing university education in many possible disciplines including medicine, law, architecture, business as well as engineering.

The University Pathway generated much excitement among prospective and current students. Many aim to get heads-up experience to enjoy university life while studying at SEEE. Partner universities are keen to offer high performing students a "preview" of their excellent academic programmes, engaging teaching and learning methodologies as well as state-of-the-art and modern facilities and campus. With insights gathered from stakeholders, SEEE commenced this initiative by jointly conceived and co-designed with National University of Singapore (NUS) and Singapore University of Technology and Design (SUTD) two separate pathways whereby selected students could read university modules during their diploma courses at the respective universities.

This University Module Pathway therefore serves to give students a unique learning experience and heads-up in having university education when they are still pursuing the diploma qualification. The innovative arrangement allows students to earn university module credits which potentially reduce the duration and cost of their university education later.

Implementing University Module Pathway – Examples of SP-NUS CP and SP-SUTD PP

In the Elective Framework, students are required to take 3 to 5 Elective modules from a basket of modules. The original course construct of a typical diploma is shown in Figure 4a. Students normally take one Elective module per semester from Year 2 onwards.



(a) Original Construct (b) Restructured Construct

Figure 4. Designing Couse Construct to incorporate University Module Pathway

The University Module Pathway uses the Elective space to create "curriculum time" within the diploma's construct. Figure 4b shows the pathway design by re-sequencing the modules resulting in having the university modules taken in the final semester in Year 3 and in lieu of SP's Elective modules. A basket of the University's Year 1 modules which are rationalised and aligned to the objectives of the diploma courses are carefully identified and incorporated in the pathway and count towards the SP's requirements for graduation in the diploma course. Students earn module credits for relevant degree programmes at respective universities. Students with outstanding results may be offered conditional admission by the university.

Deliberation on the different standard of a university module vis-à-vis a diploma-level module resulted in the implementation of grade translation to accord diploma students an upgrade equivalent to one grade point from the actual grade attained by students for their university modules taken in this pathway. Two University Module Pathways, namely SP-NUS Collaboration Programme (SP-NUS CP) and SP-SUTD Pathway Programme (SP-SUTD PP) are now on offer. Selection criteria based on academic performance and attributes which students possess are set by the respective universities. Interviews are conducted jointly by university professors and SEEE lecturers. Figure 5 shows the journey map of each pathway.

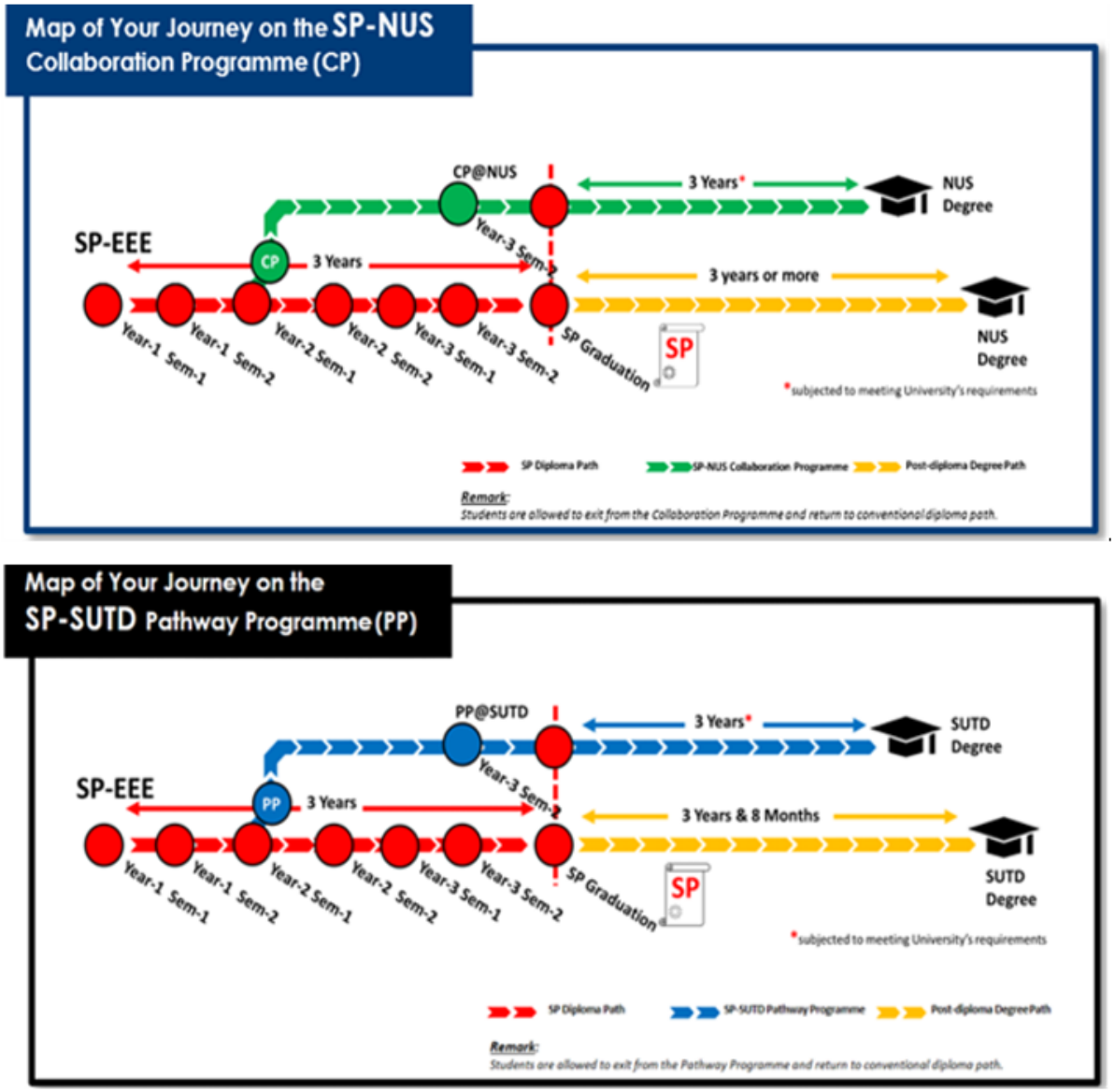


Figure 5. SP-NUS CP and SP-SUTD PP University Module Pathways

Performance of SP-NUS CP Candidates

Table 1. Academic Performance of SP-NUS CP and SP-SUTD PP Candidates

Programme	Cohort	Range of ELR2B2 Of Candidates	Entrance Performance @ End of Year 1 (Candidates' average cGPA)	End of Programme Performance (Candidates' average cGPA)
SP-NUS CP	1st	9 to17	3.923	3.926
	2nd	8 to 16	.863	Not available yet
SP-SUTD PP	1st	9 – 14	3.817	Not available yet

8 students from the pioneer cohort successfully completed the SP-NUS CP programme. Table 1 gives insights of the candidates' performance. It is worth noting that even as there is only one "single-pointer" among all the candidates with aggregate scores range from 9 to 17, these

students did very well in both their polytechnic modules and university modules. While GCE O-Level result is a typical indicator of an individual's academic ability, students in the SP-NUS CP programme show that passion coupled with well design programme with engaging learning contents and conducive environment could propel them to persevere and excel in their chosen pathway. The second cohort of SP-NUS CP students is also shown in Table 1.

Performance of SP-SUTD PP Candidates

The SP-SUTD PP was launched one year after the SP-NUS CP Programme. Table 1 shows the first cohort of SP-SUTD PP candidates' academic performance available up to the point.

Remark on University Module Pathways

SEEE Course Team has learned much from the experience in designing two University Module Pathways as CDIO standards are carefully incorporated, such as understanding the context, defining learning outcomes, ensuring integrated curriculum and integrated learning experience and others. Challenges are also abound which include alignment of the two different levels of learning and the administration of students in the pathways to ensure smooth progression from one stage to another. With early success shown by the pioneer cohort of students, the School works towards enhancing the pathway to benefit more students together with interested partner universities. This initiative has met the objectives which were set out in beginning.

ELECTIVES – CERTIFICATE AND MINOR PATHWAY

Rationale

The SP Elective Framework is designed to provide students with educational experiences aligned with SP's aspiration of developing self-directed, versatile and life-long learners. It allows students to set and achieve goals through self-exploration, shaping their own learning paths and pursuing their passions ("Elective Module", 2021). The Framework under the Choice space allows students to take 3 to 5 Elective modules which are outside of their courses' domain modules. Elective modules allow students to either broaden or deepen their knowledge and skills. Students who have completed 3 Elective modules, or 4 to 5 Elective modules in a related area of study will earn a Certificate or a Minor respectively, in addition to a Diploma. For example, Diploma in Aerospace Electronics students would normally acquire knowledge related to avionics and aerospace engineering. With the aerospace industry going through digital transformation, these students would do well to acquire additional skills in emerging technologies such as 5G, Cloud, and Artificial Intelligence which are not covered in the course, by taking relevant Electives under the Certificate or Minor Pathway.

Implementing Certificate & Minor Pathway – Examples of Minor in 5G & Artificial Intelligence of Things (AIoT)

The emergence of digital transformation and smart technologies has great impacts on industry and business. Advancements in 5G communication network, Machine Learning (ML), Artificial Intelligence (AI) and Internet of Things (IoT) lead to greater adoption that bring about productivity gain for the economy. Graduates equipped with such relevant digital skills will be well sought after by employers. A series of Elective modules covering these emerging technologies are curated. Under the Elective Framework, students who opt to take at least 4 related modules will be awarded the Minor in 5G & AIoT. The knowledge gained in the Minor

would allow students to work on real-life project when they do Internship in subsequent semester. Such skills will enhance their employability and are relevant for further study.

INDUSTRY CURRICULUM PATHWAY

Rationale

SP graduates contribute significantly to the workforce to help drive economic and technological development in the nation. The School engages and collaborates with industry to ensure that curriculum is up-to-date and students are well-trained with industry-relevant skills. The Internship module requires students to be attached to a company for 22 weeks which is equivalent to one semester of curriculum time. This is an important way to expose students to the working environment and to undertake real-world projects.

The impetus of the Industry Curriculum Pathway is that some students thrive when exposed to real-life workplace environment. They get to develop their engineer's acumen by applying CDIO concepts when working on engineering systems, processes, and services in the company. In addition, they participate in solutioning project with the aim to help improve productivity, efficiency or solve engineering problems. They apply, solidify and improve their understanding of the knowledge acquired from modules learned in the course, thereby putting theories into practice with real-life contexts and enhancing their appreciation of the chosen course of study (Martin and Wilkerson's, 2006). The success of the internship gives rise to the Industry Curriculum Pathway with the internship attachment extends from 22 weeks to two semesters or one academic year long of valuable learning in the industry.

Implementing Industry Curriculum Pathway – Example of SP-GOVTECH PTP

The SP-GovTech Polytechnic Technology Programme (SP-GovTech PTP) is shown in Figure 6. The School started this initiative with the Government Technology Agency of Singapore (GovTech) which is responsible for the delivery of Singapore Government's digital services to the public and support the implementation of the country's Smart Nation initiative. This Industry Curriculum Pathway entails a year-long Internship attachment. Besides working on project, students on this pathway are required to "learn" in industry-specific modules which are jointly curated by GovTech and SEEE. These industry-specific modules are aligned to the learning objectives and course outcomes and hence are taken in lieu of modules in the standard curriculum. In addition, two Elective modules, namely Independent Study 2 and Independent Study 3 are curated from the technological contents and real-life learning which the students would acquire in the internship attachment.

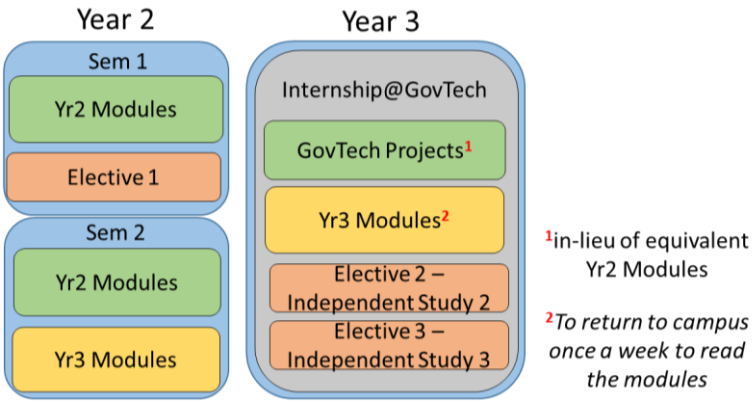


Figure 6. SEEE Course Construct incorporating Industry Curriculum Pathway

Performance of SP-GOVTECH PTP Candidates

The pioneer batch of 3 SP-GovTech PTP candidates started their full-year internship in March 2020. Table 2 shows the students' excellent academic results and their Internship grade. They managed the workload well and had enjoyed the unique learning offered by this pathway. One student remarked *"This year-long internship allowed me to work on the project from initiation to deployment, thus giving me great sense of satisfaction."*

Remark on the Industry Curriculum Pathway

Stepping out of the classroom to experience authentic industry experience definitely benefit the students. CDIO Standard 6 highlights the importance of having an environment and motivational drive that support the hands-on learning experience to apply the conceive-design-implement-operate concepts to work on products, processes, systems and services. This Industry Curriculum Pathway supports this learning experience with close partnership forged with industry partners. This initiative has met the objectives which were set out in the beginning.

Table 2. Academic performance of two batches of SP-GovTech PTP students

Batch	ELR2B2 of SP-GovTech PTP Students	Average cGPA	Internship Grade
1st	6 to 13	3.839	2 students with A grade 1 student with Distinction grade
2nd	6 to 9	3.848	Not available yet

ENGINEERING ACADEMY PATHWAY

The Engineering Academy (EA) pathway is designed to nurture engineering innovators who are self-directed, technically savvy, creative, resilient and have a growth mind-set. Students take specially curated prescribed modules that aim to deepen their engineering proficiency through in-depth training on maker-skills, engineering exploration and design, engineering solution realisation, trans-disciplinary innovation project and entrepreneurial skills. The academic profile of the EA students in cohorts 2019 and 2020 is shown in Table 3. As the EA pathway is best suited for students who enjoy hands-on learning and creating solution to every-day engineering problems, this pathway attracts students with wide-ranging academic profiles. Some graduates from the EA pathway had gone on to have their own start-ups.

Table 3. Academic profile of the EA students

Range of ELR2B2 of EA students from Cohort 2019 and 2020	Average cGPA of EA students	Range of cGPA of EA students
5 to 20	3.713	2.790 to 3.973

COMPETITION PATHWAY

The SP Elective space allows the Competition Pathway to be created which allows students to learn through the intensive training in specific domain as they prepare for competition. The learning is designed and integrated with other relevant modules and is considered as meeting the requirement for completion of SP Elective modules. Intensive trainings are conducted during the elective module time and internship period with assurance that students have acquired deep industry-specific skills and competences equitable to those acquired from modules in the standard curriculum. Such skills put students in good stead for both future employability and further study.

The School trains students for many national and international competitions. One such competition which requires high level of commitment, strong personal and interpersonal competences besides technical prowess is World Skills Competition. Exposure to such high intensity competition trains students to be technically-competent, as well as ability to handle stress at the highest level. Since 1994, SEEE students had constantly performed well in the competitions, winning a total of 28 Gold, 11 Silver, 12 Bronze and 10 Medallion in the World Skills Singapore (WSS) completion and 4 Gold, 1 Silver, 2 Bronze and 8 Medallion in World Skills (International) Competition (WSC).

PEER TUTOR CUM SUPPLEMENTARY CLASS FOR ACADEMICALLY WEAK STUDENTS

While the high ability and highly motivated students benefit from the different pathways, the academically weaker students always remain to be a concern for the School. They need help to cope with the rigorous training in engineering course. Supplementary classes for identified modules are conducted outside of the normal scheduled timetable to help students who are struggling in those modules. This programme is an integral part of the School's ecosystem in nurturing every students, including the academically weaker students to reach their potential. Students who repeat modules or pass marginally for pre-requisite modules would be placed in the supplementary class programme. The purpose is to strengthen students' understanding of fundamental knowledge and concepts to enable them to apply basic principles when they handle more advance-level modules subsequently. In addition, students facing difficulty in study would also have the Peer Tutor Scheme to find peer support. A student tutor is one who has done well in the module and he will be assigned to one or more academically weaker students. The student tutor will journey with the tutees by providing coaching in module content and imparts good study habits. Table 4 shows the statistics of students who passed their identified "weak" module upon attending the supplementary class or peer tutoring programme with passing rate of at least 80% and hitting a high of 92.5%. It is heartening to know that the Peer Tutoring and Supplementary Class scheme has helped many academically weak students.

Table 4. Statistics of students attending Supplementary or Peer Tutor Programme

Academic Year & Semester	No. of Students attending Supplementary Class	No. of Students passed Repeat modules	Percentage of Students passed Repeat modules
AY18 Sem2	31	28	90.32%
AY19 Sem1	43	37	86.05%
AY19 Sem2	25	20	80.00%
AY20 Sem1	75	69	92.00%
AY20 Sem2	88	78	86.64%
AY21 Sem1	40	37	92.50%

CONCLUSION

The creation of multiple pathways for students have provided them with choices and more control over their learning. These are keys to overcoming "boredom" with gifted students as shown in the interviews conducted by Kanevsky and Keighly (2003). As the current Gen Z students are known to thrive with challenges that connects with their personal interest, educators at all Institutes of Higher Learning need to create a more dynamic and flexible course structures and programmes that can constantly challenge the gifted and talented students (Moore, 2012), while ensuring the academically weaker ones are not neglected and left behind.

The challenge of each pathway is to maintain the attractiveness of the programme and the associated benefits to the students, in order for them to sign up and remain motivated throughout the pathway's journey.

All pathways described in this Paper have achieved the intended outcomes with validations and affirmations obtained from stakeholders such as employers, universities and governmental agencies. Students with wide range of abilities and passions, from the high potential ones to those academically weaker ones have all benefitted from the types of learning offered by the different pathways and programmes. For each cohort of students, approximately 75 to 80% of them undergo the standard curriculum, while 15 to 20% fulfil their aspirations by choosing one of those specially curated pathways, and 5% receive additional assistance in their study.

The School will continue to explore innovative ideas in designing new pathways that challenge education norms and bring the approaches to engineering education to greater level of diversity and collaboration.

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BIOGRAPHICAL INFORMATION

Toh Ser Khoon is the Director of the School of Electrical & Electronic Engineering. Under his leadership, the School continues to be a strong advocator and practitioner for CDIO, Design Thinking and Fab Lab curriculum. His current focus is on nurturing self-directed learners to be work, life and world ready. He is also interested in the use of educational technology and learning analytics for engineering education.

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