A SCHOOL-WIDE ECOSYSTEM TOWARDS NURTURING STUDENTS TO BECOME SELF-DIRECTED LEARNERS

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ABSTRACT

Engineering education and training have evolved over the years due to the rapid pace of technological advancement and changes. It is imperative for the upskilling and upgrading of engineering knowledge to keep pace with changes in technology throughout one's working life to stay relevant. This requires one to possess the Self-directed Learning (SDL) mindset and skillset to constantly seek and acquire the necessary knowledge and skills independently as part of life-long learning. To meet this objective, the School of Electrical & Electronic Engineering (EEE), Singapore Polytechnic (SP) has fine-tuned the CDIO-based curricula for all its four diploma courses to strengthen the SDL elements for its 2400 full-time and 650 part-time students. Although the SDL project was launched about three years ago with differentiated learning, the implementation was accelerated due to the COIVD-19 pandemic. To further develop the SDL mindset through independent learning, multiple pathways were introduced in which the students were able to acquire skills and knowledge outside of the classroom environment. Strengthening the SDL elements resulted in the phasing out of the lecture component in a traditional classroom delivery and replaced by asynchronous e-learning. With the appropriate structure in place to support learning, the students are required to prepare for the lessons by self-learning before attending synchronous lessons to correct misconceptions or to seek clarifications from the self-learning. Students with different learning abilities are identified using learning analytics so that differentiated instructions can be conducted for optimised student learning. The findings from the four sets of students' self-assessment surveys on their self-directedness that were conducted for one cohort of students spanning from the time when they first joined the polytechnic to their graduation will be shared. This paper will also discuss on how well the students were received by the industry during their workplace internship in the final year.

KEYWORDS

Engineering education, self-directed learning, learning analytics, differentiated teaching, multiple pathways, CDIO Standards 6,7,8,11

INTRODUCTION

The school first embarked on the SDL project in 2019 and details can be found in the CDIO2020 paper titled "Using Learning Analytics in Moulding Students to Become Self-Directed Learners" (Toh S. K., Chia, Tan, & Safura, 2020). A second SDL paper titled "Adapting CDIO Framework to Cultivate Self-Directed Learning During COVID-19 Pandemic" was published in CDIO2021 (Toh S. , Chia, Tan, & Safura, 2021). The EEE-SDL Ecosystem has since evolved, and the final version is given in Figure 1. It can be divided into two major groups with one that focuses on learning in a formal structured setting comprising asynchronous lectures, synchronous tutorial, practical sessions, assessments, and the other group where learning takes place in a less formalized framework through multiple pathways and co-curricular activity (CCA). The structured learning framework focuses on learning needs, learning goals, learning resources, appropriate learning strategies; and evaluating learning

outcomes that is largely based on research done by Knowles (1975). Differentiated learning to customize teaching and learning based on the learning abilities of the students is a feature of the framework as the school recognizes that every student is different and possesses varying degree of self-directedness as postulated by Brockett & Hiemstra (1991).

EEE-SDL ECOSYSTEM

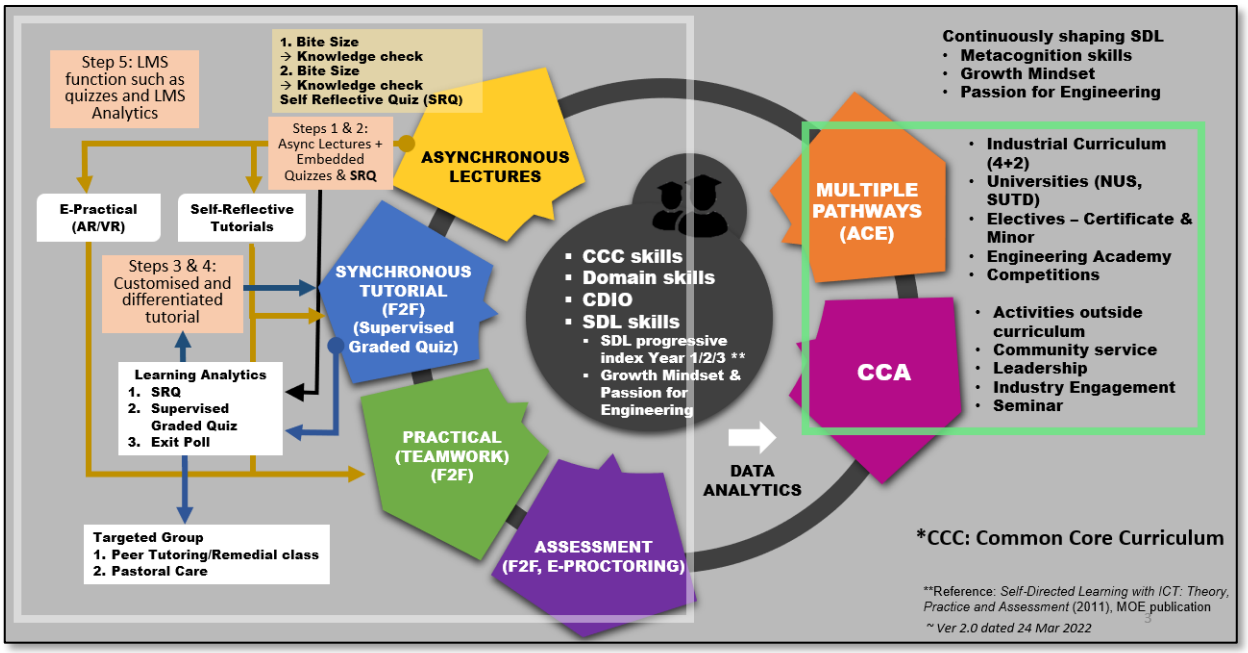

Figure 1. EEE-SDL Ecosystem

Curriculum delivery in the past comprised of three face-to-face components (lecture, tutorial, practical). New topics were taught during lectures to a large cohort of students – about 40 in media classrooms or more than 100 in lecture theatres. Tutorial lessons were scheduled immediately after lectures in smaller groups of 20 for better interaction and engagement between the lecturer and students to clarify doubts and reinforce understanding of the topics taught. The practical lessons were designed to strengthen the understanding by applying the theorical knowledge learned during the lecture and tutorial lessons.

Despite the constant exhortation to the students to prepare for the lectures by reviewing the materials beforehand, many of the students did not see a need to do so as they knew that they could cope with the lectures delivered by competent professionals. Although this approach of learning has been effective and sufficient in the past to prepare the students for a relatively stable and long working career, this is insufficient in today's working environment due to the rapid technological advances and changes. For the students to be work-ready, life-ready, and world-ready after graduation, they must become independent and self-directed learners in both their mindset and skillset.

ASYNCHRONOUS LECTURES

Face-to-face lectures were phased out and replaced by asynchronous lectures to develop the SDL mindset and skillset in the students. However, this could not be implemented overnight

since the essential support structure must be in place to ensure that the necessary assistances are available when needed. The school thus adopted a two-pronged approach to address the short-term and long-term needs in the transformation to asynchronous lectures.

Online Learning materials

PowerPoint slides developed for classroom teaching are normally a summary of the main points that required the presence of a lecturer to provide the necessary explanation and illustration. This was supplemented using textbooks for further reading by the students. With the conversion to asynchronous lectures, contents of the PowerPoint slides were modified with two objectives in mind: -

1. Bite-sized PowerPoint slides with detailed explanation
   In the short-term solution to building up the necessary support structure, the contents of all slides were now expanded to include detailed explanation for the students. Whereas in the past where a lecturer was required to fill in the gaps, these were now covered by illustrations to promote self-learning and easy understanding. The deck of slides for a topic was segmentized into 10-minute bite-size length to make them less daunting and overwhelming to learn independently.

2. Knowledge Check (KC) With Narration
   The long-term solution called for narration to be incorporated in the slides and inclusion of KC at the end of each bite-sized segment. These were mainly in the form of MCQ quizzes to test the students' understanding before they could proceed to the next segment. If incorrect answers were given, they would have to review the lesson materials again.

At this juncture, the two above objectives were met for all the modules in the school, and this numbered more than one hundred. Apart from PowerPoint, other applications like Articulate Rise and iSpring were used to develop new online learning materials. Regardless of the type of application used, these new online materials were developed based on the "bite-sized with knowledge check" rule.

The asynchronous lecture process is given in Figure 2 below.

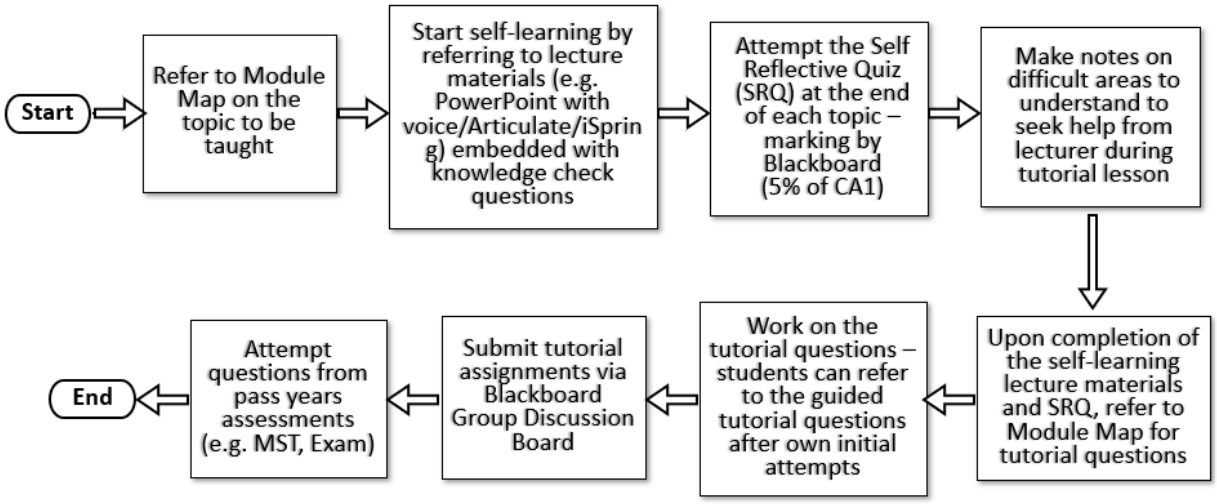

Figure 2. Asynchronous Lecture Process

In areas where the students find it difficult to understand, they are advised and encouraged to make notes and to raise these issues during the face-to-face or online synchronous tutorial lessons.

After completing a topic, the students are required to take a Self-Reflective Quiz (SRQ) that is graded. Grading based on the number of questions correctly answered is necessary as otherwise many students were be less inclined to review the online learning materials on their own. The final score for the SRQ component in the module assessment is calculated based on the average of the seven best scores.

Self-Reflective Tutorials

After completing a set of SRQ, the students will next attempt tutorial questions for the topic on their own. If they face any challenges in solving the questions, they can refer to a set of "Guided-Solutions" posted on the Learning Management System (LMS). This provides guidelines on how best to approach the questions to solve them without giving them the actual solutions.

The ability to solve the problems given in the tutorial questions can boost the students' confidence and encouraged them to attempt past years' Mid-Semester Test (MST) or Examination questions.

SYNCHRONOUS TUTORIAL LESSONS

The synchronous tutorial can either be conducted face-to-face or online in smaller class size of about 20 students. Although the focus of these tutorial lessons is to address any issue that the students faced during their asynchronous self-learning, another aim is to be able to customise the teaching to benefit students of different learning abilities by leveraging on the use of learning analytics. Pilot runs to fulfil the latter objective was implemented for one module comprising 40 classes during two semesters.

Three different approaches in the conduct of the tutorial lessons to meet the objectives outlined above were implemented in the past, and these are discussed below.

Short Period Tutorial

This approach is for 1½ to 2-hour long tutorial lessons and by far the most prevalent since many tutorial lessons are time-tabled for this duration. A list of prepared MCQ quizzes covering the whole topic is presented to the students during a lesson and the lecturers conduct just-in-time mini-lectures in areas where many of the students are unable to provide the correct answers. To implement this, a PowerPoint add-in called “ClassPoint” - similar to applications like “Socrates” or “Kahoot” - is used to provide the necessary interface. Since ClassPoint shares a common platform with Microsoft PowerPoint application, conducting the lesson by integrating the MCQ quizzes with the PowerPoint slides resulted in a seamless and less disruptive flow during delivery. Supervised weekly graded quizzes (WGQs) are also conducted to evaluate the students’ learning during each lesson and the results contributed to the final grading of a module.

Long Period Tutorial

Modules with allocated tutorial time of more than 2 hours enable the lecturer to implement a more creative approach during the lesson. A typical class of 20 students is divided into 4 groups comprising students with different learning abilities. Four different questions are assigned to each group and members work together as a team to determine the solution. The role of the team leader, being the brightest in a group, is to ensure all members can understand and able to explain the solution. If need be, the lecturer will brief the leader in advance on the approach to tackle the question if the group makes little progress after some time. Time is set aside during the lesson for the presentation of the solution by the weakest student in a group. In this approach, the students not only learn how to apply the theories into practice through collaboration with their classmates but also strengthened their soft skills in the areas of teamwork, communication, and presentation.

Pilot Run Using Learning Analytics

This approach is largely like the “Short Period Tutorial” approach but with a small variation. The process in the implementation of this “Real-time Student Feedback” is given in Figure 3 below. Exit polls are conducted 30 minutes before the end of a lesson. Results from the SRQ, WGQs and exit polls are collected during a lesson and processed using learning analytics to identify the students’ learning ability as well as finding out the areas that they require further assistance. The process of uploading and crunching the data and outputting the results is speeded up using Robotic Process Automation (RPA). Based on the results obtained during a lesson, the lecturers can identify students of different learning abilities. Questions of varying difficulty levels are then assigned to the students according to their learning abilities. This approach helps to engage the whole class during a lesson without neglecting the needs of the higher-ability students who are given more challenging questions to attempt. About 15 minutes towards the end of a lesson, the lecturer re-visits areas of the topic where the students have not fully understood to provide further clarification. (Mark & Chong, 2021)

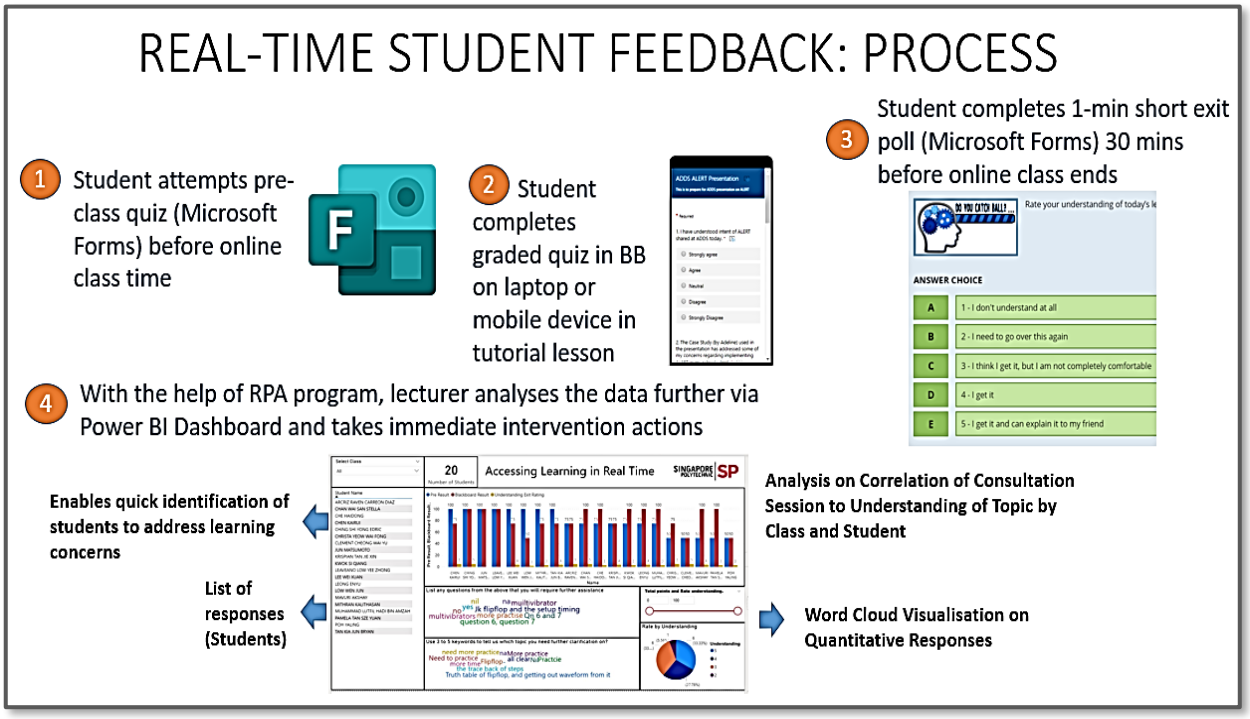

Figure 3. Real-Time Students' Feedback Process

Peer-learning and Supplementary Lessons

Prior to entering the polytechnic, student learning takes place in classrooms with teachers adopting the "sage-on-the-stage" approach. Students are used to having the teachers feeding them the necessary information in their learning. When faced with the need to change their learning style, it is understandable that some of them will find it difficult to cope. Safety nets are thus in place for students who needed more help in their learning, and these are in the form of a peer-tutoring network and supplementary lessons. In the former, senior students who had earlier taken and done well in the modules are roped in to help the weaker ones while additional lessons called "Supplementary Lessons" are conducted for these students by specially selected lecturers who are known to be more caring and dedicated.

LAB PRACTICAL LESSONS

A good engineer needs to be able to apply, create, troubleshoot, and ultimately make things work. As the students in the school are trained to become engineering professionals, practical lessons are therefore essential in their trainings. A typical two-hour practical lesson in the past could be broken down into three parts – first 30 minutes for the lecturer to give a briefing on the objective, theoretical background to support the experiment and the expected results. The next 60 to 90 minutes would be used by the students to conduct the experiment while the remaining time was for the lecturer to discuss the results obtained and finally to summarise the whole practical lesson. The practical lessons were conducted in pair of two for a class of about 20 to 22 students.

Videos on practical lessons were developed amidst the COVID-19 pandemic when a lock down was imposed. These videos highlighted the objective, circuit set-up and procedures to

obtaining the desired results for the students to have an overall picture on what the practical session was all about. (Boon-Seng, et al., 2021)

When the students were able to return to the campus, the total number of students attending a practical session was reduced by half to between 10 to 11 students for each practical session in line with COVID-19 safe distancing measures. As the students were now required to view the practical videos before attending the practical sessions, the total time required for a typical experiment was reduced. This reduction in time allowed the experiment to be expanded to cover more areas in a practical session. Conducting a practical session for half the class had its advantage as unlike in previous case when students worked in pairs, the weaker students could no longer rely totally on their partner to carry out the whole experiment as they were now required to conduct the practical session on their own. More importantly, by having to review the practical videos before joining a practical session, the student takes a pro-active approach in their learning, and this progressively can lead to developing an SDL mindset.

ASSESSMENTS

Two types of summative assessments are in place for examinable modules, where one is scheduled during mid-semester and the other at the end of the semester. During the early days of the pandemic, the school rolled out a plan to ensure assessments could continue to take place even under the extreme situation of a lockdown when the students had to stay at home. This was in the form of an online e-proctored assessment that was developed in-house with compatible rigour and academic quality vis-a-vis in-person assessments where candidates are in the same site and supervised by invigilators who monitor them during the test. Even when the students were allowed to return to campus to take their assessments, one module was selected to undergo online e-proctored assessment to maintain the readiness of the school's ability to response to any future lockdown.

MULTIPLE PATHWAYS

All students take three years to complete a diploma course in the Singapore Polytechnic with a 6-month semester-long internship programme where the students are attached out to the industry in their final year. The school also recognises that students have different preferences and aspirations based on their passions and interests. In this regard, the school offers multiple pathways to the more capable ones to complete their diploma course of study by acquiring the necessary knowledge and skills through different platforms and experiences in order to stretch their potentials. Summaries of the multiple pathways are given below.

Industrial Curriculum Pathway (4+2)

A typical three-year diploma course of study takes six semesters (each lasting six months) to complete with the final semester taken up by the internship program and is denoted as 5+1. The school is always scanning the horizon in search for established and well-respected organisations that can provide relevant real-life industrial training to its students and when such organisations are found, only the exceptional students who are capable of coping with the project and work demands are selected. This is a year-long programme consisting of two semesters (4+2) with the modules to be taken in one semester being replaced by the relevant project and work experiences in the organisations. Students' involvement in industry projects and work attachments are curated to meet module learning objectives with the added benefit of gaining industry-based professional experience.

University – Level Modules Pathway

The National University of Singapore (NUS) and the Singapore University of Technology & Design (SUTD) are two of the more prestigious universities in Singapore where the admission criteria are stringent. The students joining this pathway takes three modules offered by the universities in their campuses and these modules replace three of the electives in the polytechnic that the students are required to take as part of their course of study. When students on this pathway joined the two universities after graduation, they are exempted from having to take the same modules again and this can help to shorten the time required for them to graduate.

Electives – Certificate & Minor Pathway

These are part of the Singapore Polytechnic's elective framework that provides all its students with learning opportunities to set and achieve learning goals through self-exploration, shaping own learning paths and pursuing their passions. The learning experiences help them in their development as self-directed, versatile, lifelong learners.

While a certificate is awarded if a student completes three electives that are related to their course of study, the student receives a minor if they choose electives that has no link to their courses. The minor provides a choice for the students individually to pursue an additional discipline beyond their domain core to enhance their portfolio for future employability and studies. Students' knowledge, and competency in this second selected domain will be deepened to complement their domain core and attributes such as creativity and innovativeness can be demonstrated in their resulting portfolios.

Engineering Academy Pathway

The Engineering Academy (EA) Programme was conceived to challenge the selected students to be engineering innovators where they will learn to create workable solutions to solve real world problems. They will learn how to figure out the right questions to ask, take charge of their own learning and work through uncertainty. This is to be accomplished by collaborating with peers from other engineering diplomas, learning about Design and Business, acquiring prototype skills, and working closely with industry and university partners.

Competitions Pathway

In general, competitions help the students to expand on their portfolios, develop new skills or deepen existing skills, and for the school to benchmark the standards of its students against both local and overseas institutions. These competitions ranged from domestic to regional and international such as World Solar Car Challenge 2019, WorldSkills Competitions, Robocup Asia-Pacific 2019, 14th International Standards Olympiad 2019, Greenpower UK Challenge 2019, National Smart Nation Competition 2020, Virtual Robocup Asia-Pacific 2020, Robocup World 2021, International Standards Olympiad (2019, 2020 and 2021), World Skills Singapore 2021, Robocup Asia-Pacific 2021.

CO-CURRICULAR ACTIVITIES (CCA)

Activities outside curriculum

The polytechnic and school organize many events outside of the students' coursework throughout the year to provide the opportunities for the students to develop their leadership,

interpersonal, teamwork, and organisation skills. Some examples are the Freshmen Orientation Programme (FOP), Graduation Ceremony, Open House for potential new students, Educational and Career Guidance Day as well as EEE Alumni Day. During these events, students are recruited to serve as ambassadors and tasked to organise some of them.

Another area where the students can contribute is in the Peer Tutoring Scheme. These students are usually the exceptional and brighter ones who will promote good study habits to the weaker students and coach them to work towards better academic performance.

Community Service

One of the school's missions is for its students to become socially responsible citizens who are compassionate to genuinely care and have respect for other people especially the under privileged and senior citizens. In this regard, students are required to serve the community in each semester by planning and organizing two-hour interactive activities for residents in welfare homes and community centres. During these sessions, students engage the residents by socializing and interacting through food, games and providing listening ears especially to the senior citizens.

Leadership

Students who exhibit leadership qualities are nominated to attend the SP-Leadership Programme where they will be trained on fundamental knowledge and skills on personal leadership for personal effectiveness, team leadership for leading teams and working with others and servant leadership for developing others. The aim is to stretch the potentials of these student leaders to take on challenges at higher levels as part of their development progression.

Industry Engagements & Seminars

Over the course of their studies in the polytechnic, the students are given many opportunities to attend various talks, seminars, workshops, and technical conferences by professionals from the different industries under the auspices of the Educational Career & Guidance (ECG) module. Through these events, the students can gather industry insights and understand the types of skills required in the different industries.

SURVEY ON SDL INDEX MEASURING PROGRESSION IN SELF-DIRECTEDNESS

The self-assessment survey to measure the self-directedness of the students at different milestones in their studies consists of four surveys. The first survey is targeted at new students before the start of their courses while the other three are conducted at the end of their first, second and final year of study. Each survey is made up of 14 statements (see Table 1) on a 7-point Likert scale. The set of statements can be divided into three groups, the first two groups relating to intrinsic and extrinsic motivations respectively, and the remaining ten on SDL readiness that were adapted from the work by Tan, Divaharan, Tan and Cheah (2011).

Table 1. Students' Self-assessment Statements for SDL

Statements S1-S2 Intrinsic Motivation	
S1	I prefer learning materials that really challenge me so I can learn new things.
S2	I prefer learning materials that arouse my curiosity, even if it is difficult to learn
Statements S3-S4 Extrinsic Motivation	
S3	I want to do well in my studies because it is important to show my ability to others.
S4	Getting a good grade is the most satisfying thing for me.
Statements S5-S14 Dimensions of Self-directedness	
S5	I set learning targets for myself.
S6	I normally ask questions when I am not sure about my learning.
S7	I always look for more information to help me understand better.
S8	I always make a list of what I need to do for my learning.
S9	I usually complete my assigned tasks on time.
S10	I often try to understand where I go wrong in my learning.
S11	I try different ways to solve problems on my own at all times.
S12	I have a habit of applying what I learned to other topics or areas.
S13	I always seek out what is required of me beyond the syllabus of my module.
S14	If I try hard enough, I will understand the learning materials.

One cohort of students who joined the polytechnic as new students in the 2019/2020 academic year has completed the four surveys. The results are given in two different plots – one focussing on motivation trend (Figure 4) while the other on their self-directedness (Figure 5).

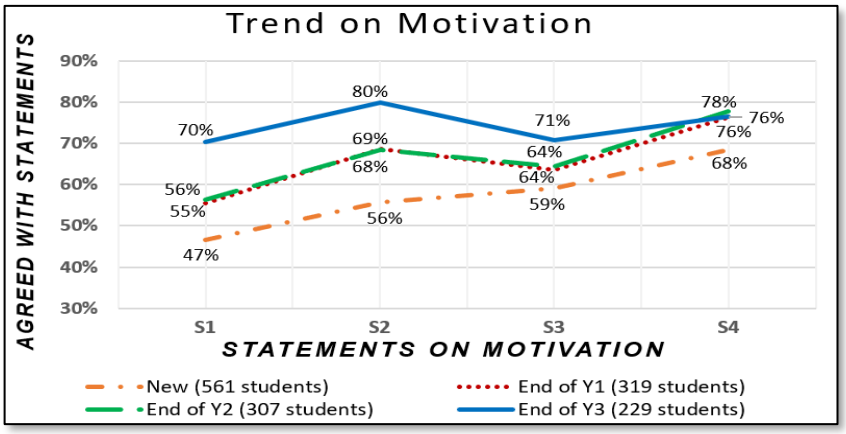

Figure 4: Students' self-assessment indicating heightened motivation.

For the first two intrinsic motivation statements (i.e., S1 and S2) based on the plot given in Figure 4, it is evident that the students have shown positive and significant improvements. For example, from the time that the students joined the polytechnic to the end of their 3-year courses, there has been an increase in 23% of students who relish learning materials that challenge them to learn new things. Likewise, an improvement of 24% over the same period for S2 means that the students are motivated enough to want to learn out of curiosity regardless of the difficulty level. It is thus heartening to note that more students are now more intrinsically motivated when it comes to acquiring new knowledge and skills after completing their courses in the polytechnic.

Results on extrinsic motivation also registered improvements albeit not as significant as the earlier ones. The percentages for S3 and S4 have increased from 12% and 8% respectively. These measures centred on the students' personal satisfaction in showing their ability to others and in getting good grades.

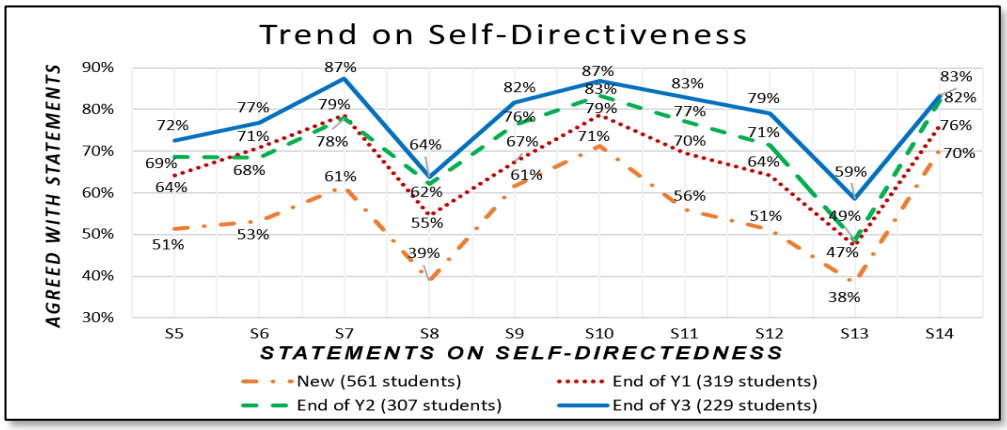

Figure 5. Students' self-assessment indicating heightened self-directedness

Evaluating the dimensions of self-directedness in the students were based on the statements from S5 to S14. From the results obtained in Figure 5 above, it is comforting to note that the students have benefitted from the three years in the polytechnic as can be seen from the overall trend lines as eight of the ten statements (i.e., S5, S6, S7, S8, S9, S11, S12, S13) registered more than 20% improvement while the remaining two (i.e., S10, S14) were well above 10%. The highest percentage of 28% for S12 demonstrates that more students have developed the good habit of applying what they have learned to other topics or areas. More students are now prepared to try different ways to always solve problems on their own as shown by the 27% improvement for S11. S7 also sees a marked improvement of 26% and this relates to the students always looking for more information to help them understand better.

STUDENTS' GENERAL PERFORMANCE DURING INTERNSHIP

Internships in the relevant industry are valuable experiences for both the students and the hosting organisation as the former can benefit from the work experiences while the latter gets to evaluate in depth a potential future employee (Martin and Wilkerson's, 2006). The majority of the third-year cohort in the school are attached out for a six-month internship in the industry during their final semester. Surveys are conducted with the hosting organisations to gather feedback on the students' performances at the end of the internship. Over six semesters from AY2019-20 S1 to AY2021-22S2, the average number of organisations who responded to the surveys was 208. Two pertinent questions posed in the surveys were on whether the hosting organisations were keen to take in more interns in the future and whether the interns have done well to be considered for long term employment in their organisations after graduation. Based on the results from the surveys given in Figure 6, the hosting organisations were satisfied with the performance of their interns as more than 93% expressed their interest in accepting more interns in the future while at least 74% were willing to offer them employment after their graduation.

Interns are paid an allowance by the hosting organisations during their internship and guidelines are set on the minimum amount to be paid. If the hosting organisations had experienced positive and significant contributions from past interns and were confident of the

quality of future interns, they were encouraged to pay a higher allowance. On this note, it is heart-warming to note that the number of organisations who were willing to pay higher allowances to the interns had increased progressively from 51% to 57% over the past three semesters.

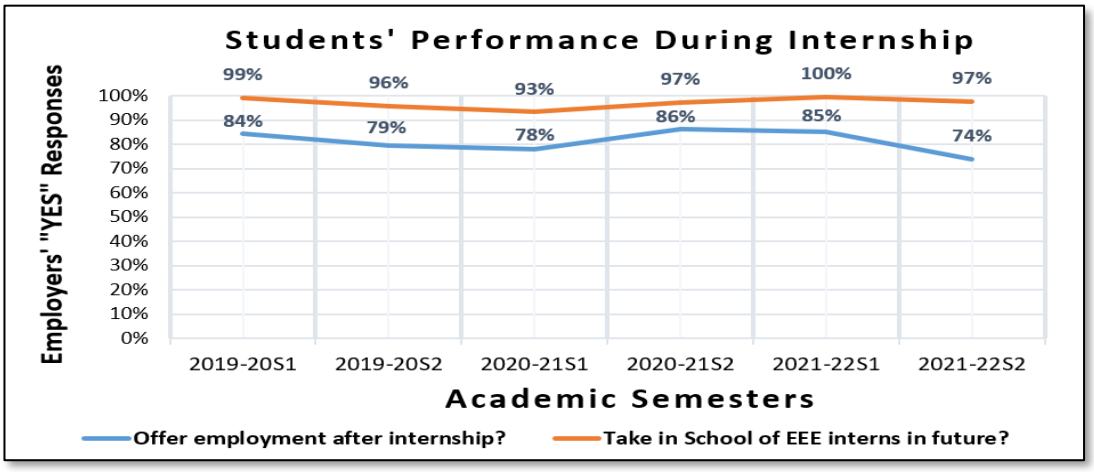

Figure 6. Results of Survey on the Performance of the Students During Internship

CONCLUSION

The acid test in any polytechnic course is how well its graduates are accepted by the industry since the students are educated and trained to fulfill the industry's needs and demands. Based on the contributions of the interns in the industry, hosting organisations were generally happy and satisfied with the interns' performances as evident from the fact that many of them were prepared to offer employments to their interns after graduation, willing to take in more interns in the future and paying the interns above the recommended minimum guidelines. This positive and encouraging responses from the hosting organisations is a testament of the new EEE-SDL ecosystem's capability in producing graduates who can perform and excel in the work environment.

Over the last three years, ten of the School's top graduates had won prestigious national-level scholarships which was a feat that was never achieved in the past before the EEE-SDL ecosystem was established. The other impactful outcome was in the peer tutoring scheme and pastoral care network which have helped more than 80% and 74% respectively of the at-risk students to progress successfully to the next stage of their courses.

The findings of the students' self-assessment surveys measuring the progression in self-directedness have also affirmed that the whole-school approach in the cultivation of SDL is progressing well on the right track. During the COVID-19 pandemic lockdown from April to June 2020 when Home-based Learning was enforced, and the subsequent measures introduced in the classroom for safe-distancing after the lockdown was lifted, the students were able to cope relatively well based on the comparison of their performances in the summative assessments with preceding semesters. As this can be considered as the second acid test for the EEE-SDL ecosystem, the school is heartened that the inculcation of the SDL mindset and skillset has contributed to the students' ability to face challenges and cope with uncertainties in their learning journeys.

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BIOGRAPHICAL INFORMATION

Toh Ser Khoon is the Director, School of Electrical & Electronic Engineering, Singapore Polytechnic. Under his leadership, the School continues to be a strong advocator and practitioner for CDIO, Design Thinking and FabLab-based curriculum for the Engineering diploma programmes. His current focus is on nurturing and preparing learners to be self-directed and work-life and world-ready. In the area of teaching innovation, the emphasis will be on the use of educational technology and the application of learning analytics for engineering education.

Tan Hua Joo joined the Singapore Polytechnic in 1991, serving in various portfolios such as Academic Resource & Development Manager, Course Manager and Head of Teaching & Learning (T&L) Unit. His interest is in T&L matters particularly in nurturing and developing students to become independent learners. He is also passionate about using educational technology in his teaching to help the students in their learning.

Safura Anwar has been with Singapore Polytechnic as a lecturer since 1986. After serving in various portfolios, she presently works with a team of highly experienced and dedicated staff in the Teaching and Learning unit in the School of EEE, who share a common passion to work with colleagues and students alike, so that they become better self-directed learners in all aspects in their own capacities and to role model SDL for others.

Chia Chow Leong is a Deputy Director at the School of Electrical & Electronic Engineering, Singapore Polytechnic. His current portfolio is in Course Management and Student Development. He oversees the planning, development and implementation of full-time courses and continuing education & training (CET) courses in his school. He has a strong interest in conducting action research to enhances students' learning and strengthen staff pedagogical competence. He also plans programmes to nurture students and develop them to become self-directed learners.

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