Spiral Project Based Learning Curriculum Design Model & Implementation: A Case Study

Conference Paper · September 2020

4 authors, including:

Keng Wah Choo
Nanyang Polytechnic

Wui Keat Yeoh
Nanyang Polytechnic

Spiral Project Based Learning Curriculum Design Model & Implementation: A Case Study

Keng Wah CHOO, Wui Keat YEOH, Tiehua DU and Kwai Fern LAM

Biomedical Engineering and Materials Group, School of Engineering, Nanyang Polytechnic

ABSTRACT

The Diploma in Biomedical Engineering (DBE) offered by the School of Engineering at Nanyang Polytechnic introduced three Applied Learning Tracks (ALTs) in 2016 after a major curriculum review, namely the Biomedical Engineering & Design, Biomedical Instrumentation and Control and Biomedical Manufacturing Quality and Process. This paper aims to share the design and implementation of a Spiral Project Based Learning (SPBL) pedagogical approach based on CDIO concepts in building the competences required for biomedical engineering professionals, in particular for the Biomedical Instrumentation and Control ALT. In this approach, learners are trained in key Knowledge, Skills and Attitude (KSA) for computer programming, microcontroller application and biomedical signal processing over a three-year diploma programme, through a SPBL that is designed to build up the KSA from lower level to the higher level spirally, by revisiting previous topics before new topics are introduced. This approach has proven to help learners in scaffolding their learnings throughout the 3-year DBE programme. It has also improved leaners' retention of knowledge gained in the first two years of their studies and be able to apply them confidently in their third year's studies. Learners were also more ready in honing their skills during their final year projects. The paper shares as well some of the challenges faced during the implementation and proposes action plans to address them.

KEYWORDS

Spiral Curriculum, Project-based Learning, Active Learning, CDIO Standards: 1, 3, 5, 7, 8.

BACKGROUND

Introduction to Diploma in Biomedical Engineering

The Diploma in Biomedical Engineering from the School of Engineering at Nanyang Polytechnic went through a major review in 2016, taking into consideration the changing landscape in healthcare and medical device manufacturing industries in Singapore, as well as the emerging technologies and advancement in these fields. As the result of this review, basing on the updated CDIO standards (Crawley, 2011), three Applied Learning Tracks (ALTs) were created to nurture the next generation of biomedical engineers. These ALTs are the Engineering & Design, Instrumentation and Control and Quality and Process as shown in Figure 1.

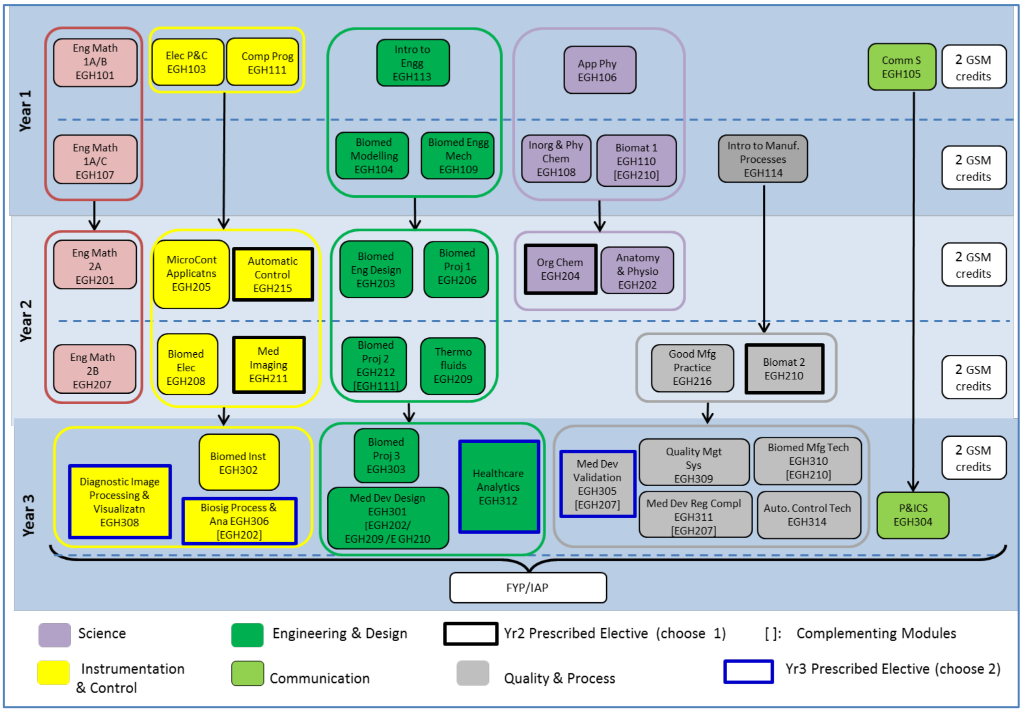

Figure 1: DBE Integrated Curriculum Map

Core Instrumentation and Control Competencies

The key learning outcomes to be built through this Instrumentation and Control ALT include the following underlined Course Educational Objectives as given in the following:

DBE Course Educational Objectives:

- Be employed with relevant and <u>current knowledge as well as skillsets</u> to support the needs of the Biomedical industry
- <u>Be effective in the design & development cycle and processes involved in medical devices and instruments</u>, and in quality and regulatory compliance in GMP work environment
- <u>Embrace a passion for lifelong learning</u> and pursue further education and/or professional training programmes
- <u>Be innovative and enterprising</u>, working in a multi-disciplinary team in a professional and ethical manner

Specifically, through this Applied Learning Track, the focus was to enhance competences in designing and developing biomedical instrumentation and control solutions. Traditionally, three core modules were used for this purpose, namely Computer Programming, Microcontroller Application and Biosignal Processing & Analysis, and they were taught in separation over the three years curriculum. It was expected that the modules were able to build up the competencies in each domain and learners were able to integrate the knowledge and skills, and able to apply them subsequently when the course requires those knowledge and skills. While this approach seemed logical where learners learn and apply their knowledge gained in each of the modules, there were challenges faced in this approach when it came to integration of knowledge and skills.

Challenges in Existing Delivery Model

This section aims to share the challenges faced in the existing model used in delivering the ALT modules. Firstly, it was observed that many learners were not able to retain the knowledge gained in the previous year and apply them into the subsequent year due to lack of integration and continuity between the modules. This was especially the case when Computer Programming is concerned. In the existing model, learners were taught key programming feature and semantic during the lecture and develop codes to solve problem statements during the tutorial and practical sessions. The assessment used to focus on the ability of the learners to troubleshoot codes with bugs built in. Learners would also work on mini projects towards the end of the module term. However, it was observed that when embarking on second-year ALT module, learners spent a significant amount of time revising and re-learn what were taught in the previous terms. Additional hours as much as double the time were spent by the leaners facing these issues.

Secondly, the use of Assembly programming languages in the Microcontroller Application module has also created some challenges for the learners. As Assembly is a new language to most learners, and it is harder to understand, code and debug when compared to higher level programming languages. As a result, learners spent a significant amount of time on the semantic of the Assembly language and trouble-shooting their codes in the practical sessions, of which they should have spent focusing on the microcontroller features, peripherals and its applications. At this stage of the studies, the focus should be on the microcontroller system design and implementation, which the existing approach was lacking in meeting the goals.

Thirdly, the codes developed in the Microcontroller Application year-2 module were a combination of C and Assembly language, running on 8-bit Microcontroller platform. These codes were not easily portable to platforms of higher complexity. Assembly language is platform and hardware dependant. Unlike higher level languages, Assembly language cannot be transferred from one embedded platform to another. This model would impede the implementation of integrated curriculum as a variety of more complex embedded platforms could be used for their final-year projects or during their internship programme at companies. This outcome was not desirable as leaners were not to seamlessly build on and apply their knowledge gained in their studies.

Finally, through interaction with industry and graduates to solicit inputs in our survey for curriculum review, feedbacks were received on the need for our graduates to be able to handle embedded platforms and programming languages of higher complexity. The graduates should be better prepared in system-level design and integration skills, good knowledge in application development process were also expected.

After considering the challenges and industry feedback, a team was set up to search for a new model to better prepare our graduates in meeting the industry needs.

DESIGNING THE SPIRAL PROJECT BASED LEARNING MODEL

During the curriculum review process, the course development team has explored the Conceive-Design- Implement-Operate (CDIO) Standards and Syllabus as well as the Project Based Learning (PBL) model for engineering education, with the aim to devise a novel and effective learning model for a more effective learning experience.

CDIO and Spiral Project-Based Learning

The School of Engineering at Nanyang Polytechnic adopted the CDIO pedagogical approach for the design of engineering programmes. The integrated curriculum map implemented in the Diploma in Biomedical Engineering was also developed based on the principle of CDIO, where the complete cycle of product development and contextualised practical-oriented teaching approaches were infused into our curriculum. On the other hand, there are rising interest in implementation of PBL in which learners learn by actively engaging in real-world and meaningful projects (Buck Institute for Education, 2020). In the PBL approach, projects are the platform for learners to build competencies, and to relate disciplines to each other in analysis and identification of problems as well as the problem-solving process.

Studies have been carried out to analyse and compare these two pedagogical approaches: Conceive-design-implement-operate (CDIO) and Project-Based Learning (PBL). It was highlighted that while the two approaches share many underlying values, they only partially overlapped as strategies for educational reform (Edström & Kolmos, 2014). The study has also pointed out that PBL and CDIO could play compatible and mutually reinforcing roles, and thus can be effectively combined to reform engineering education.

In addition to CDIO and PBL, the development team has also looked into the Spiral Curriculum teaching strategy in scaffolding the learning activities. This Spiral Curriculum was developed by cognitive theorist Jerome Bruner (Bruner, J. S., 1960), emphasizing the importance of revisiting the same topics several times throughout the course; at each return to the topics, deeper level and higher complexity should be learned; and prior knowledge should be utilized when a topic is returned to so that they build from their foundations rather than starting anew.

In our new approach, Spiral Curriculum and Project-Based Learning are used in an integrated manner, to build up learner's competencies over the three years. The idea is that each time a learner encounters a topic, the learner expands their knowledge or improves their skills level progressively. When new topics are introduced, the previous knowledge and skills acquired are revisited, before they continue to build up the next level of knowledge and skills. The continuity is ensured through repeating the topics as the learner progresses through the integrated curriculum. The Project-based Learning serves as the vehicle to integrate the knowledge and skills of the learners into projects to solve real-life problems, and to enhance the learning outcomes.

Key Principles in Designing the SPBL Curriculum Model

Three key components of the Spiral Project-Based Learning (SPBL):

- that the competencies must be introduced from year 1 and deepened over the next two years using integrated curriculum
- that the project-based learning is used as the platform for integrating and building up learner's competencies in the applied learning track
- that newly introduced learning activities must revisit previous foundational topics and deepen the knowledge and skills as learners progress

In building up of the competency, we use the Bloom's Taxonomy where learning outcomes are defined based on the Cognitive, Affective and Psychomotor skills (Bloom, et. al., 1956). These skills are often referred to by educators as Knowledge (Cognitive), Skills (Psychomotor) and Attitudes (Affective), or in short, the KSA. To achieve these learning outcomes, there are 4 delivery modes introduced in the curriculum, namely the Lecture, Tutorial, Practical and

Blended Learning. Both the lecture and tutorial are carried in a didactic learning manner to provide learners with the required foundational knowledge. It is effective in using the tutorial to conduct formative assessment to evaluate learners understanding on the concepts taught and to provide opportunity to leaners to practice and reinforce their understanding of the topics through work examples. The Blended Learning is also a mandatory delivery mode, encouraging learners to carry out research assignment, build up specific knowledge through self-directed learning and complete self-assessment to gauge their learning.

Practical sessions are provided for learners to apply their knowledge and build up skills in critical thinking, problem solving, teamwork, among other 21st century skills, through solving of thematic problem statements. Thematic problem statements are problem statements that are extracted from biomedical industry, to provide learners the context and opportunity to apply their knowledge and skills to develop solutions that solve problem (part of a bigger problem statement) of different level of complexity. This scaffolding mechanism is put in place to build up learner's competencies and confidence in working on projects over the three years, and to prepare them in solving authentic problem in their final year project. The building of this practical skills is achieved through a Spiral Project-Based Learning (SPBL) model, where the practical components of the three modules are closely linked and integrated to form the final solution to a larger problem statement.

Last but not least, we deployed the integrated curriculum approach by linking modules that have explicit connections among related and supporting content and learning outcomes, to provide an integrated learning experience over the three-year curriculum. Often, we observe learners were not able to recall subjects that they have learnt in the previous terms. In some instances, they were not aware of the application of concepts in the later part of the curriculum, making the learning not as effective as it should be. An example of the effort in linking the relevant and related modules is shown in Figure 2.

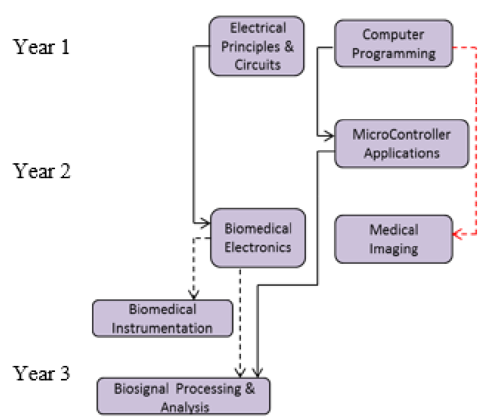

Figure 2: Direct and Indirect Links across 3 years ALT curriculum (--- indirect link)

Selection of Suitable Modules for SPBL Curriculum Model

The team has identified the following three modules as the core subjects where this model could be deployed, namely the Computer Programming in year 1, Microcontroller Application in year 2 and Biosignal Processing and Analysis in year 3 of the Biomedical Engineering curriculum. These three modules are selected for the obvious reason that the computer programming and microcontroller application form the major components of any medical devices that requires instrumentation and control. For instance, an infusion pump would require an on-board microcontroller that reads in the parameters set by clinician though a user interface, and the it would dispense the medication through a pump that is programmed to carried out the task according to the setting given. The Biosignal Processing and Analysis is selected for the reason that the any vital signal captured by the medical devices, such as the Electrocardiogram (ECG) or Electromyogram (EMG), would require a microcontroller to read in the data from a probe, digitised using the Analog-to-Digital Converter (ADC), and sent to a computer for further processing and analysis, and again computer programming and microcontroller design and development know-how are required to build a complete embedded device for these devices. With the modules being identified, the proposed design of the teaching model is shown in Figure 3.

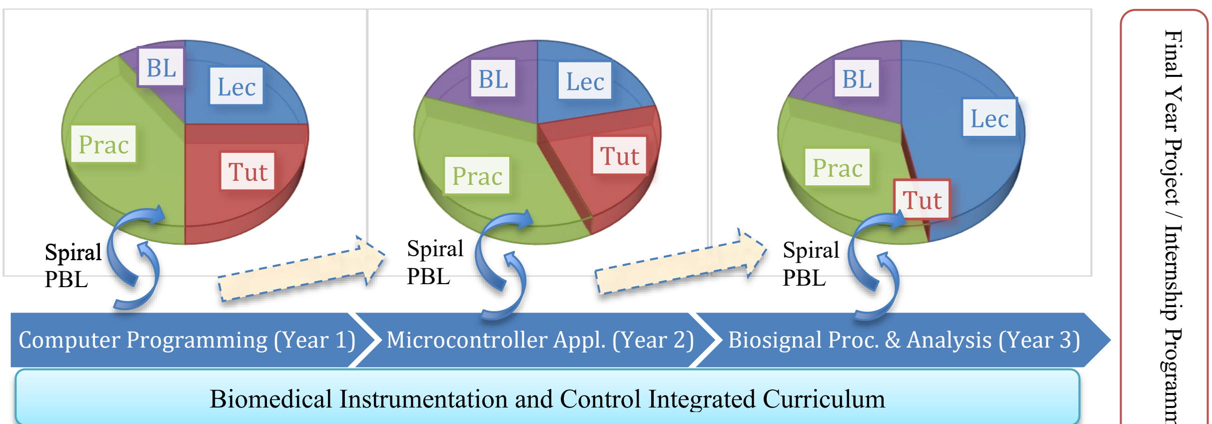

Figure 3: Spiral Project-based Learning Model

Implementation of the SPBL Pedagogical Model

Teaching & Learning Platforms

One of the key considerations in this implementation was to decide on the programming language and embedded platform. The curriculum development team has evaluated the suitability various embedded programming languages including C, Phyton, C++, etc. According to a 2016 survey by IEEE Spectrum, C took the top spots for being the most popular and used programming languages in embedded systems (Cass, 2016). C Programming language was chosen for the fact that majority of the embedded instrumentation and control platforms are also using this as the main programming language (TIOBE, 2020; UbuntuPIT, 2020). It was decided that C programming would be the language to teach the key principles of Computer Programming.

The embedded platform is another item that required review. The Microcontroller Application module had been using ATMEL 8051 from the beginning of the course. The ATMEL 8051 was used due to its simplicity in its architecture and assembly instruction. However, with increasing adoption of higher complexity features in modern medical devices and instrumentation, such as the Internet-of-Medical Things (IoMT) and edge computing, the team had decided to use a 32-bit embedded controller, the ARM Cortex processor, which is more powerful and suitable for application both for richness of features and ability to support solution of higher complexity. Specifically, the Arduino DUE built with ATMEL ARM Cortex-M3 CPU is used (refer to Figure 4). The microcontroller has 54 digital input/output pins, of which 12 can be used as PWM outputs, 12 ADC (Analog to Digital Converter), 4 hardware serial ports for interfacing, 2 DAC (Digital to Analog Converter). The same platform can be used for year 2 and year 3 curriculum to build up learner's competencies in microcontroller application.

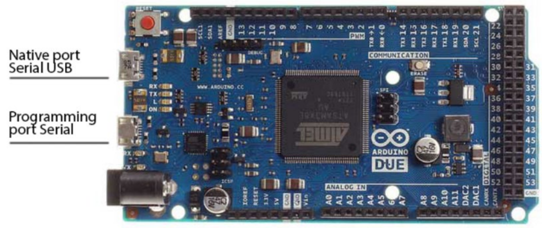

Figure 4: ARM Cortex-M3 Platform

Instructional Design for Computer Programming

The instructional design of the practical sessions for all three modules are closely linked. For the Computer Programming module, leaners are given problem statements, where team of two learners were formed to work on the projects during their practical session. Using these projects, leaners are able to build up knowledge in topics including Computer Software Systems, Elements of a Program, Control Structures, Arrays, Functions through the Practical Sessions allocated to the Computer Programming module. Each of these topics are introduced in practical sessions, revisited from one practical session to another, with increased level of complexity to deepen their skills in computer programming. At the end of the module, learners are evaluated based on their ability to complete the assignment. This foundational module focuses more on the I-O parts of the CDIO curriculum.

Instructional Design for Microcontroller Application

In the Microcontroller Application module, learners are to build up knowledge and Skills in developing embedded system software using modern development tools which interface with external hardware to solve real world problems. In designing embedded system software, the skills level for computer programming built in year 1, has to be elevated to allow the computer to interface with external hardware other than the keyboard and screens. In this aspect, embedded system hardware concepts are introduced in lecture and problem statements are introduced for their practical sessions, similar to the approach used in Computer Programming module. For instance, in the first two practical session, learners build on the foundation on hardware through configuring and controlling general-purpose input-output (GPIO) ports using embedded software programming. As they move on to the following weeks, hey need to configure the same port for other hardware with higher complexity, including sending message through serial communication, controlling of an actuator, and sensor interfacing. Towards the end, all these embedded software and hardware that they have developed, are to be integrated a form a smart biomedical systems or devices, such as a smart walking cane, wearable or ECG monitoring applications. This is to encourage integration of knowledge as well as building up teamwork, creative thinking and problem-solving skills. Learners are to present their completed assignment to a group of assessors and peers, and assessment will be carried out to measure their performance.

A High-level Language (HLL) programming tool is introduced to help leaners to acquire the concept of Finite State Machine (FSM), which is a conceptual tool used to design computer system(refer to Figure 5). A State Chart Graphical Tool was introduced where learners create and visualise a Finite State Machine (FSM) easily. Once an FSM is designed, C programming codes can be generated automatically. This tool has not only shifted the focus of the learners to system level design, but also significantly reduced the time learners spent on coding. More importantly it provides the learner a better overview of the system being developed, and understanding of the key concepts that they implemented for the project. The design of the curriculum focuses on the D-I-O parts of the CDIO curriculum.

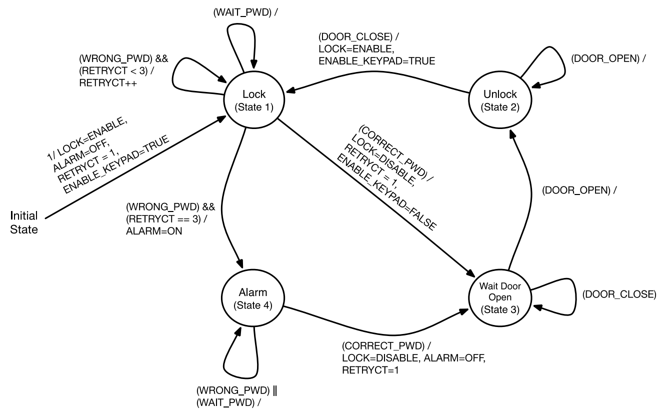

Figure 5: Finite State machine (FSM) for Electronic Lock System

Instructional Design for Biosignal Processing and Analysis

The 3rd year module Biosignal Processing and Analysis focuses on learners' competences in capturing of biosignal through a process covering signal conditioning, signal amplification, digitization and filtering. The digitized signal is then analysed by computing and visualising the spectrum of the signal. The concepts are taught through lecture and blended learning sessions while the practical sessions require learners to make use of the embedded system know-how developed in their second year to acquire physiological signal such as ECG (Electrocardiogram) and PCG (Phonocardiogram). In this new approach, we adopted an in-house developed hardware as the platform to be used in project for integrating learning spirally. The hardware given to the learners were a wearable device designed by DBE learners who have graduated in the previous year. In this embedded device, the, as shown in Figure 6, is a hardware platform having two built-in sensors, one sensor for ECG and another one for PCG. Learners were required to recognise some of the hardware and review some of the codes developed in the first two years to better understand the specifications of the platforms.

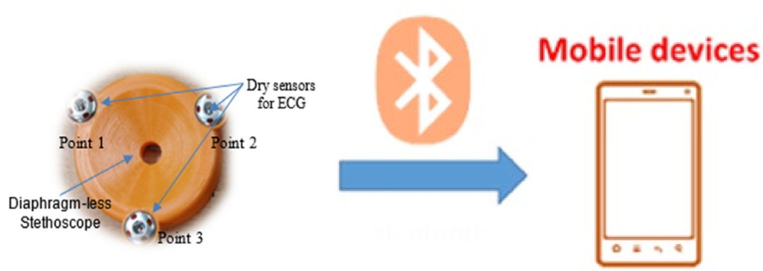

Figure 6: Embedded Device for ECG and PCG Monitoring

Subsequently they will design and create codes based on the GPIO and ADC know-how acquired in their Microcontroller Application Module. The practical sessions further step up the requirements by getting the learners to configure the communication channel and writing a simple programme to record them onto a mobile device, such as a smartphone. The signal captured is then analysed in a computer system using a MATLAB software, by designing the required filtering (refer to Figure 7) and visualization codes. Again, the learners have to use their computer programming skills acquired in the first two modules over the first two years of the course, and build up the signal processing, analysis and visualization codes, which are of higher complexity. Key concept such as time & frequency domain representations, digital filter design, Nyquist's sampling theorem and others are covered in lecture and blended learning sessions. The project allows learners to apply these knowledge and skills through a project during practical session. This is an important feature of the SPBL model, such that learners see a completed project by building and integrating functional hardware and computer programming spirally over all the practical sessions. In this model, none of the practical sessions are independent from each other, and the linkage made between each practical session ensures learners build up competences gradually to meet the eventual learning outcomes. In this module, the complete CDIO cycles were introduce according to CDIO curriculum.

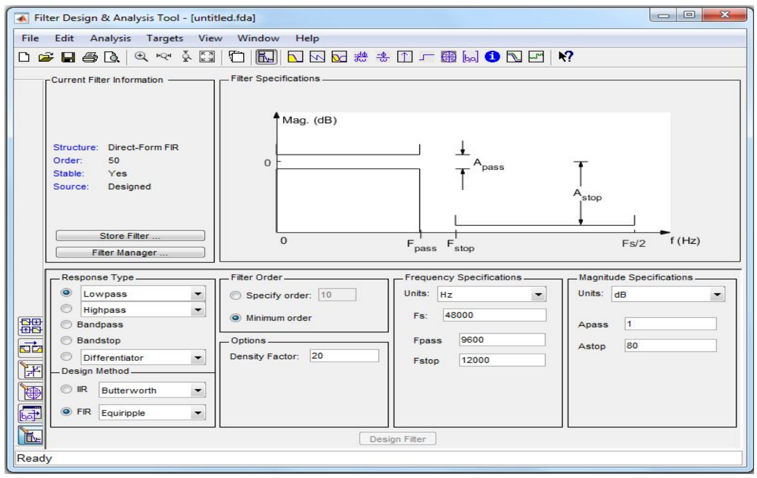

Figure 7: Digital Filter Design and Analysis Tool

EVALUATION AND DISCUSSION

We gathered feedback regularly from the learners as well as their module performance. To triangulate the observation on learners' performance, feedback from the lecturers were also gathered. Generally, it was observed that learners were more motivated and enjoyed the spiral project-based practical sessions where they built up competences in developing real-life and practical projects for biomedical instrumentation and control.

Module Feedback

The learners' feedback was gathered after every completion of the module over the last three years as these revised modules were gradually being offered to replace the old curriculum. The feedback uses a Linkert scale of 1 to 4 with 1 representing Strongly Disagree and 4 representing Strongly Agree. From the feedback received, we observed a strong indication over the support for the new delivery model, as summarised in Figure 8.

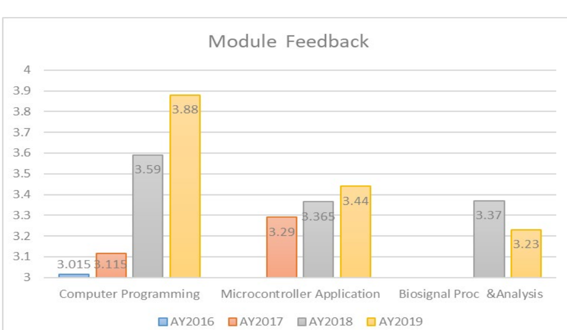

Figure 8: Module Feedback from Learners

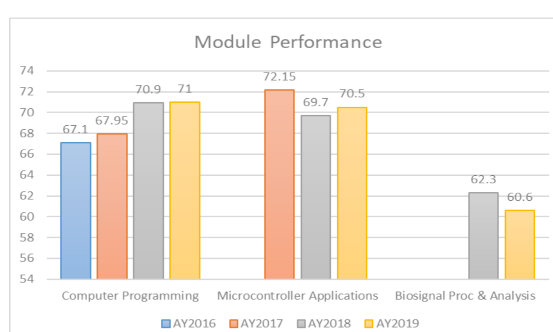

Figure 9: Module Performance of Learners

In the first-year Computer Programming module, which was introduced in AY2017, we saw a good improvement in the feedback received. It started with score around 3.0 in AY2016, gradually improved to over 3.8 at the end of AY2019. The lecturers have fed back that learners felt a bit difficult to remember the syntax and data structure of C, but after 15 weeks of project works, especially after the practical sessions, the leaners were able to master C programming language much better. We observed increased in motivation when learners were able to solve challenges faced bit by bit, and eventually complete a working function for their projects.

In the second-year Microcontroller Application module, where the rollout was implemented a year later in AY2018, similarly the learners have given better feedback over the new delivery model, albeit not as significant the increase as compared to Year-1 Computer Programming module. It has improved from 3.29 to 3.44 over the two years of implementation since AY2018. The lecturers have fed back that the learners were seen struggling in handling the rather complex embedded platform as that would be the first time they were working on such hardware and system configuration. However, when they were more familiar with the hardware, they were observed to be more motivated when High Level Language was used for coding. The focus was on implementing the system-level design and not on the semantics of the programming language as they faced in first year.

In the third year Biosignal Processing and Analysis module, after the first round of implementation, a drop in the module feedback was observed. We further investigated the feedback to understand the cause of the drop. From the analysis, we found out that learners felt the module loading were higher than other module as the project implementation has taken more time than being allocated for the practical sessions. This has created impact on their preparation for the final assessment outcomes. Another observation found from the investigation was that the blended learning provided was not able to help learners achieve the intended learning outcomes. Nevertheless, some learners did feedback that they enjoyed the project work. One of them has noted that the module is one of the most interesting modules in year 3. Others said that they were more motivated as they were able to capture their own biosignal for processing. Filtering the real physiological signal gave them a sense of achievement in developing a medical device in this module. With this mixed acceptance of the new delivery model, a review has been initiated to see how to balance learners' workload.

Module Performance

The team also tracks the learner's module performance closely to measure the effectiveness of the approach. In addition to having introduced the new module content and delivery module, the assessment components were also adjusted to align to the learning activities and outcomes. The team expected some form of positive impact on the performance of the learners and the results are shown in Figure 9. For the Computer Programming module, the correlation between the Module Feedback and Module performance is linear. Learners are generally satisfied with the delivery model and their performance have also improved. The module performance for Microcontroller Application seemed to have dipped a little bit before it rebound. The same phenomenon was observed in Biosignal Processing and Analysis module, a slight drop in learners' performance. This year-3 module has also received declined in the module feedback as shown in the previous section. A review is on-going to review the loading given to them. The table of specification of the modules where the assessment coverage and weightage are specified was reviewed. An over-emphasis on the written exam, a weightage that is more than 50% of the total assessment, might have caused the drop in the learners' performance as a significant amount of time were spent on the project practical sessions. A review is on-going to re-balance the distribution of the assessment components.

Final-Year Project

The ultimate objective was for learners to apply key competences in biomedical instrumentation and control acquired in solving real-life problems. We observed that learners were more willing to take up intelligent product development (microcontroller-based) projects in their final year, some are shown in Figure 10. With the inclusion of SPBL, the learners are more prepared in to complete the CDIO cycles of product development. The introduction of high-level language (HLL) and more complex embedded platform in the second year has also helped learners in tackling systems and devices which are more complex in nature.

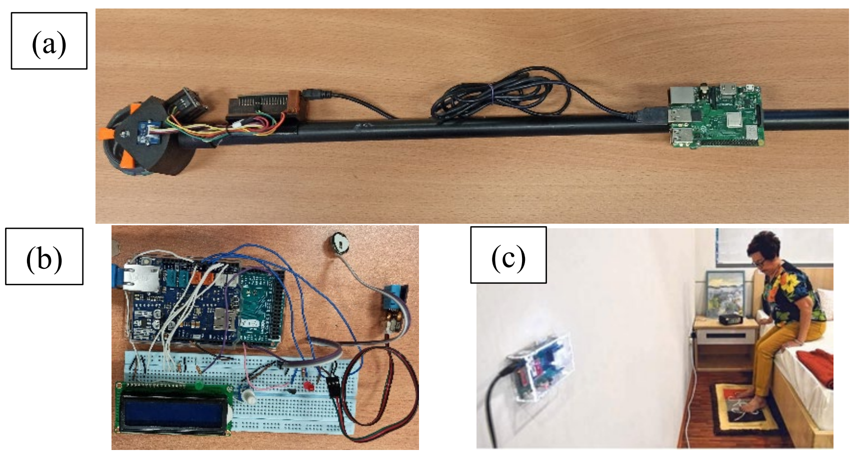

Figure 10: Final year projects (a) Smart Cane for Visually Impaired Individuals, (b) Internet of Medical Things for Physiological Signal Sensing, (c) Smart Mat for Activity Monitoring of Aged

CONCLUSION

The preliminary results of the implementation of SPBL model has been encouraging. It has been able to help the learners in acquiring the needed competences. The results are observed from feedback from the learners and teaching staff, and the performance outcomes. We do see new challenges faced by the new model, such as higher loading for the teaching staff and learners. We felt that the additional efforts put in by the learners were meaningful as they get to learn and apply their knowledge in solving real-life problems. The team will continue to fine-tune and monitor the effectiveness of the model. The development team will investigate the loading of the practical sessions, the blended learning materials, and the assessment components of the modules to improve the learning experience of the learners.

REFERENCES

Bloom, et. al. (1 November, 1956). *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain.* New York: David McKay Co Inc. Retrieved from Endnote: https://endnote.com/

Bruner, J. S. (1960). The Process of Education. *Harvard University Press*. Retrieved from Word Help & Training: https://support.office.com/en-us/article/create-a-bibliography-citations-and-references-17686589-4824-4940-9c69-342c289fa2a5

Buck Institute for Education. (09 Jan, 2020). *What is PBL?* Retrieved from PBLWorks: https://www.pblworks.org/what-is-pbl

Cass, S. (20 Jun, 2016). *The 2016 Top Programming Languages*. (J. Björkqvist, K. Edström, R. J. Hugo, J. Kontio, J. Roslöf, R. Sellens, & S. Virtanen, Editors) Retrieved from IEEE SPECTRUM: https://spectrum.ieee.org/computing/software/the-2016-top-programming-languages

Crawley, E. F. (2011). The CDIO Syllabus v2.0. An Updated Statement of Goals for Engineering Education. In J. Björkqvist, K. Edström, R. J. Hugo, J. Kontio, J. Roslöf, R. Sellens, & S. Virtanen (Ed.), *Proceedings of the 7th international.* Technical University of Denmark, Copenhagen,. Retrieved from http://julkaisut.turkuamk.fi/isbn9789522166104.pdf

Edström, K., & Kolmos, A. (2014). PBL and CDIO: complementary models for engineering education development. *European Journal of Engineering Education*.

TIOBE. (8 January, 2020). Retrieved from TIOBE Index for January 2020: TIOBE Index for January 2020

UbuntuPIT. (8 Jan, 2020). Retrieved from Top 15 Best Embedded Systems Programming Languages: https://www.ubuntupit.com/top-15-best-embedded-systems-programming-languages/

BIOGRAPHICAL INFORMATION

Dr Yeoh Wui Keat is a Specialist and Senior Lecturer from School of Engineering, Nanyang Polytechnic. Beside his academic duties, he is actively involved in funded research projects and industry projects related to his research interests, covering AI, video analytics, edge computing.

Dr Du Tiehua is a Senior Specialist and Senior Lecturer from School of Engineering, Nanyang Polytechnic. He is actively involved in research and development in the areas of medical image processing, and artificial intelligence, as well as educational research.

Ms Lam Kwai Fern is a Senior Lecturer from School of Engineering, Nanyang Polytechnic. He is actively involved in academic activities and research and development in the areas of biomedical signal processing, and medical device instrumentation and control.

Dr Choo Keng Wah is a Deputy Director in the School of Engineering, Nanyang Polytechnic. He is actively involved in industry project development and management, biomedical research and development projects, protection and commercialization of IPs, engineering education benchmarking, education quality assurance and accreditation.

Corresponding author

D Choo Keng Wah
Nanyang Polytechnic
180 Ang Mo Kio Avenue 8
Singapore 569830.
65-65500587
choo_keng_wah@nyp.edu.sg