EVALUATION OF SPIRAL CURRICULUM FOR CHEMICAL ENGINEERING USING CDIO FRAMEWORK

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ABSTRACT

This paper shares the experience of the Diploma in Chemical Engineering (DCHE) of Singapore Polytechnic (SP) in using the CDIO Framework to guide the design of spiral curriculum for chemical engineering students. In this spiral curriculum model, simple concepts are introduced to the students first, which are then revisited and re-construed in a more in-depth and elaborated manner throughout the three-year course. The CDIO learning outcomes are intertwine into the context of learning to support the levelling up of knowledge and skills from one semester to another, from one module to another, while integrating critical thinking skills with disciplinary knowledge to provide a more holistic approach to engineering education for our students. The paper first introduces spiral curriculum for chemical engineering and explains how the modules are sequenced within the three-year course based on the complexity of concepts, context of learning as well as opportunities for application and integration of knowledge. Then, it describes the use of block teaching as a means to deliver the spiral curriculum where knowledge and skill competencies are levelled up via a cluster of modules offered within a semester. DCHE had two runs of block teaching and the third run is currently in-effect. Qualitative and quantitative surveys were carried out to evaluate the effectiveness of block teaching on student learning and student performance in assessment across different cohort of students in the first two runs. A z-test was used to compare student academic performance at 5% significance level and statistically there are no significance difference. It was found that generally student were able to connect the concepts taught from one module to another better compared to a non-spiral curriculum. Some improvement plans had been implemented based on the feedback of the first two runs and these are discussed in the paper. Faculty teaching staff who facilitate the learning with students also plays an instrumental role in the spiral curriculum where they must have the ability to provide the integrated learning experiences to students and help students make connections between the concepts that are taught in different modules and across semesters. So, it is important that faculty members are able to deliver more than one subject or area of study. While there are benefits for using block teaching to aid student learning, there are challenges and trade-offs which are further discussed in the paper. In the last section of the paper, it outlines the broad areas where we strive to continue to study the effect of block teaching in future cohort of students to improve the delivery of the spiral curriculum and support student learning.

KEYWORDS

Chemical Engineering, Spiral Curriculum, Block Teaching, Standards: 3, 11, 12

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called “courses”. A teaching academic is known as a "lecturer", which is often referred to a as "faculty" in the universities.

INTRODUCTION

The Diploma in Chemical Engineering (DCHE) course from Singapore Polytechnic (SP) had adopted CDIO as the basis for revamping its curriculum since 2007 and its “CDIO-enabled” curriculum was introduced for the first time in April 2008 for students in the Academic Year 2008/2009 cohort (Cheah, 2009). There was a need to shift the curriculum model, which was largely content driven and taught in silos with little connectivity between modules, to one focusing on key concepts fundamental to understanding and in a more integrated format [Standard 3 – Integrated Curriculum]. In addition to integration of discipline-specific knowledge in the curriculum, various generic skills such as teamwork, communication and critical thinking were integrated into carefully designed learning activities in laboratory sessions or assignments to core chemical engineering modules.

Since then, several national initiatives such as Singapore Skills Framework and Industry 4.0 took off which led to further review of the course to re-design and deliver appropriate learning content to meet both existing and emerging skills required for the changing industry needs and work roles [Standard 12 – Program Evaluation]. The redesign of the chemical engineering curriculum and its CDIO experiences after years of implementation were documented in various earlier papers, e.g. Cheah, Phua & Ng (2013) and Cheah & Yang (2018).

As part of a continual improvement over past efforts, the most recent revamp of the DCHE course took place in 2017 which led to the adoption of the spiral curriculum model for its course structure for students in the Academic Year 2018/2019, in response to providing a more systematic structure to build up student competencies using the CDIO approach while ensuring the curriculum retains its integrated form.

The process undertaken by the Course Management Team to carry out the transition had been described by Cheah & Yang (2018). The DCHE curriculum model shown in Figure 1 illustrates the progressive development of key competencies over the diploma’s 3-year duration.

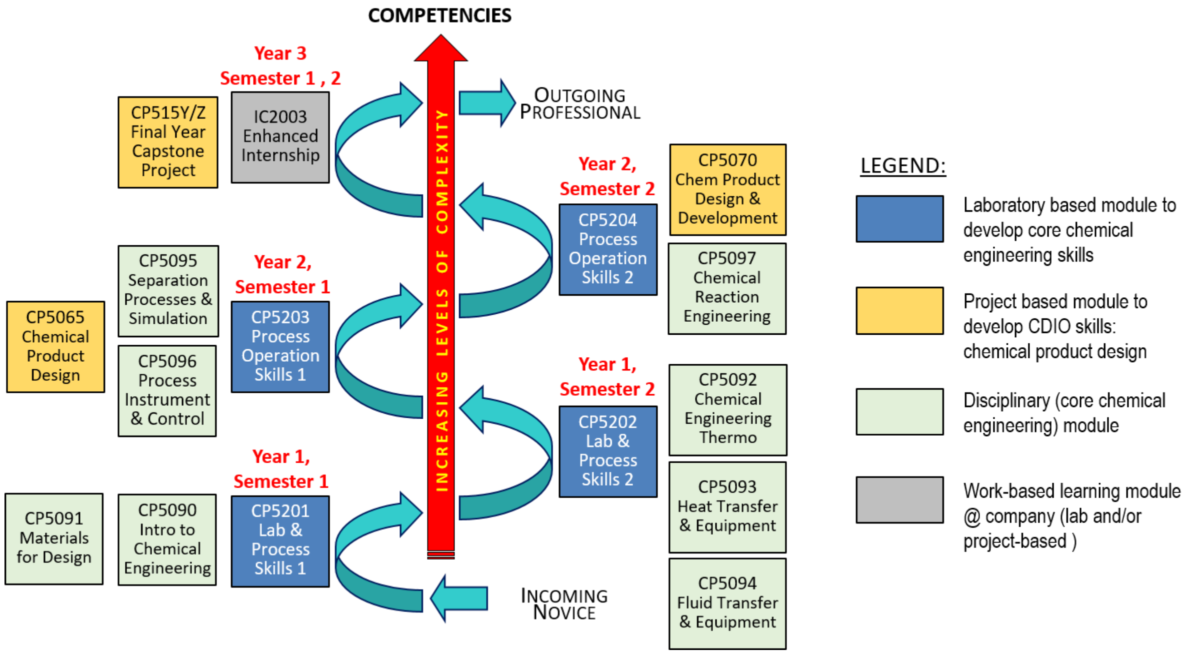

Figure 1. The DCHE Spiral Curriculum Model

One of the key changes in supporting the spiral curriculum is the way of teaching the core modules. More specifically, we implemented the practice of “block teaching” in which core modules are covered in a more compact manner, with greater contact hours per week but in lesser number of weeks; instead of over the entire semester (Cheah & Wong, 2019).

At the time when this paper is published, DCHE had two runs of block teaching which were in Academic Year 2018/2019 (first run) and Academic Year 2019/2020 (second run). The third run is currently in-effect. Hence, this paper presents the challenges faced in the implementation of block-teaching, improvements made to address the shortcomings, findings on students’ perception of block teaching in terms of learning effectiveness and comparison of student performances across different cohorts as a result of the transition.

WHAT IS A SPIRAL CURRICULUM?

Spiral curriculum is a concept widely attributed by Bruner (1960), who refers to a curriculum design in which key concepts are presented repeatedly throughout the curriculum, but with deepening layers of complexity, or in different applications. Bruner (1960) believes that “a child of any age at any stage of development is capable of understanding complex information if the subject is effectively taught in some intellectually honest form”, notably via a spiral curriculum. In another words, the information is structured so that complex ideas can be taught at a simplified level first, and then re-visited at more complex levels later on. Therefore, subjects would be taught at levels of gradually increasing difficultly – hence the spiral analogy. Such treatment allows the earlier introduction of concepts traditionally reserved for later, more specialized courses in the curriculum, after students have mastered some fundamental principles that are often very theoretical and likely to discourage students who are eager to apply the concepts they are learning to real-world applications.

The spiral model of learning is lauded by Sheppard et. al. (2008) as “the ideal learning trajectory with all components revisited at increasing levels of sophistication and interconnection. Learning in one area supports learning in another.” In such a model “…the traditional analysis, laboratory, and design components would be deeply interrelated: engineering knowledge remains central but is configured to include both technical and contextual knowledge; competencies of practice, laboratory, and design experiences are integrated into the whole, as are professionalism and ethics. The overarching goal of the program would be to position students for a lifetime of continuous learning and growth.”

EFFECTIVENESS OF SPIRAL CURRICULUM IN ENGINEERING EDUCATION: WHERE IS THE EVIDENCE?

Applications of spiral curriculum have been reported in the literature centered around the teaching of mathematics (e.g., Cowan, et. al., 1998; Singapore Ministry of Education, 2007), basic sciences (e.g. Grove et. al., 2008) and in the field of medical education (e.g. Harden & Stamper, 1999; Brauer & Ferguson, 2015; Ovadia-Blechman, et. al., 2016).

Application of spiral curriculum in engineering education had been reported by Collura et. al. (2004) for multi-disciplinary engineering program, Gomes et. al. (2006) and Gupta et. al. (2008) for undergraduate chemical engineering degree courses and Neumann et. al. (2017) for chemical engineering master degree program.

Fraser et. al. (2019), in a study comparing spiral and traditional curriculum in preparing medical students to diagnose and manage concussions, noted that the spiral curriculum promotes a strong understanding and retention of knowledge. Likewise, Gomes et. al. (2006) and Gupta et. al. (2008) believe that spiral curriculum is a superior learning approach because it allows students to “master each increment of subject in hierarchical sequence before going on to the next” (Gupta et. al., 2008). In fact, Gomes et. al. (2006)’s study reveals that there is significant increase in student engagement within the broader learning process. Masters & Gibbs (2007) finds the spiral curriculum to be very effective for online learning if the practice is used consistently.

Herrick et. al. (2003) reported on the use of spiral curriculum to optimize the students’ learning process and retention rates of students in electrical engineering. Similarly, the trends reported in Gomes et. al. (2006) and Gupta et. al. (2008) studies suggest that curriculum reform and implementation of the spiral curriculum lead to “valuable gains” in chemical engineering degree programs (Gupta et. al., 2008), enhance student motivation and self-directed learning (Gomes et. al., 2006). Moreover, there are meaningful improvements in retention rates, graduation rates and student performance in general after applying spiral curriculum principles (Neumann et. al., 2017).

DiBiasio et. al. (1999) reported on their work in chemical engineering, noting that the spiral curriculum has improved students' learning of technical content, teamwork and communication skills as well as their identification with chemical engineering as a major and a profession. The technical proficiency of the students from the experimental group (i.e. using taught spiral curriculum) is at least equal to that of traditionally taught students, while their attitudes toward chemical engineering and towards the value of teamwork are considerably more positive than those of traditionally-taught students.

Noting that many applications of spiral curriculum have shown positive effect on student learning, including DCHE, there are various challenges in its implementation, which are further elaborated in this paper.

BLOCK TEACHNG IN DCHE

Block teaching is used as a means to deliver the spiral curriculum in DCHE course where one module is sequence one followed by another. It was first rolled out in Academic Year 2018/2019 in which students started the semester with *Chemical Engineering Thermodynamics (CP5092)* module, followed by *Heat Transfer & Equipment (CP5093)* and *Fluid Flow & Equipment (CP5094)* modules. The block teaching schedule is illustrated in Figure 2, where the semester consists of 18 weeks inclusive of 3 weeks of mid-semester vacation (Week #9 to #11).

With reference to Figure 2, the module content of *Chemical Engineering Thermodynamics* was the first module to be covered in the semester and a test was administered on Week #3 where about 50% of the module content had been covered. The purpose of the test is to allow faculty members to gauge student learning. The examination was scheduled at the end of the semester as a summative assessment for the module. As the module was categorised as an examinable module in Academic Year 2018/2019, based on the institutional requirement, the examination could only be held at the end of the semester which is either on Week #19 or Week #20. To ensure that students stay connected with the module, a one-hour lesson was crafted out in each week from Week #12 to Week #17 to provide revision and prepare the students for the examination.

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<tr><td colspan="20">Week Number: Semester 2, Academic Year 2018/2019 (Run #1)</td></tr>
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<tr><td colspan="5">CP5092 (60 hrs)</td><td colspan="3"></td><td colspan="7"></td></tr>
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Figure 2. Schedule of Block Teaching in Academic Year 2018/2019 (Run #1) & Academic Year 2019/2020 (Run #2)

Leveraging on the concepts covered in *Chemical Engineering Thermodynamics*, in particular, the 1st Law of Thermodynamics, the remaining two modules, *Heat Transfer & Equipment* and *Fluid Flow & Equipment* were taught in parallel. These two modules focus on the application of 1st Law of Thermodynamics in different context which allowed students to build on the fundamental concept and develop understanding in higher complexity. This systematic approach resulted in an integrated curriculum that involves linking a core module with key concepts from other core modules while integrating critical thinking skills. Hence, an integrated test for *Heat Transfer & Equipment* & *Fluid Flow & Equipment* modules was administered in week #14 to evaluate the application of knowledge from both modules. A scenario-based approach and various pedagogies were used to design the assessment questions where scenarios reflecting possible real-world work tasks or environments provide the context for students to utilise their prior knowledge when appropriate and demonstrate knowledge transfer from one module to another (Cheah, 2009). The survey results discussed at later part of this paper also showed that students were able to integrate the knowledge learnt.

EFFECT OF BLOCK TEACHNG ON STUDENT PERFORMANCE

The Course Management Team examined the impact of block teaching on student performance. So, the academic performance of the students in the first run of block teaching (students from Academic Year 2018/2019) was compared to an earlier cohort (students from Academic Year 2017/2018) without block teaching. The z-test is used to compare the mean score of the cohort with and without bock teaching at 5 % significance level using the data in Table 1.

It was found that the performance of students are comparable with no significance difference in the key performance index (mean score and pass rate) at 5% significance level for all three modules. Pass rates have been consistent with and without block teaching. This means that even when the modules are covered in a more compact manner, the students achieved similar academic performance as compared to modules covered over the entire semester.

After the first run of block teaching, some improvements were made to the block teaching schedule. The academic performance of the students of Academic Year 2019/2020 (second cohort with block teaching) was compared with students of Academic Year 2018/2019 (first cohort with block teaching) and 2017/2018 (the cohort without block teaching), which are also summarised in Table 1. Once again, the performance of students are comparable with no significance difference in the key performance index (mean score and pass rate) at 5% significance level. Pass rates have been consistent with and without block teaching. This means that student academic performance is independent of the duration used to cover module content.

Table 1. Comparison of Key Performance Index with and without Block Teaching in Academic Year 2018/2019 (run 1) & Academic Year 2019/2020 (run 2)

	CP5092 Chemical Engineering Thermodynamics			CP5093 Heat Transfer & Equipment			CP5094 Fluid Flow & Equipment		
Curriculum	Non-block	Block Run 1	Block Run 2	Non-block	Block Run 1	Block Run 2	Non-block	Block Run 1	Block Run 2
Mean Score	71	69	71	74	75	68.4	72	74	75
Pass Rate	99.3%	98.4%	96.1%	99.2%	98.4%	97.6%	98.4%	100.0%	97.6%

SURVEY RESULTS ON BLOCK TEACHING

The Course Management Team has vested interest to understand students' perception on the block teaching model. Hence, a quantitative survey was conducted at the end of each semester. Specifically, students were asked to indicate on a 5-point Likert scale the extent to which they agree or disagree with the following statements with 1 being Strongly Disagree and 5 being Strongly Agree.

Question 1: With the block teaching format, I was able to see connections between what was taught in the 3 different modules

Question 2: The block teaching format enables me to better understand the basic engineering concepts

Question 3: The block teaching format challenges me to think in depth (e.g. analyse, compare and contrast, evaluate)

Question 4: The block teaching format reduces the amount of varied information to deal with at any one point in time and hence increases my ability to focus attention on specific topics

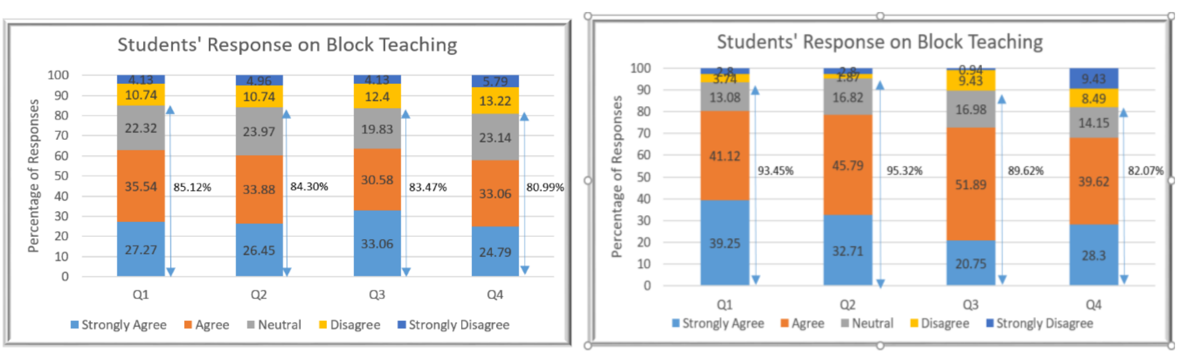

Figure 3. Students' Responses on Block Teaching in Academic Year 2018/2019 (left) and Academic Year 2019/2020 (right)

Figure 3 (left) shows the response obtained from the first cohort of block teaching with a response rate of 89.6%. Based on the responses obtained, 85.12% of the students agreed that they are able to “see the connections” among the three modules where block teaching enhances students’ ability to integrate knowledge learnt and strengthen their ability to solve problem of higher level of complexity. In another words, the integrated curriculum had enabled students to link the key concepts from one core module to other core modules.

84.30% of the students agreed that the block teaching format enables them to better understand the basic engineering concepts and 83.47% of the students agreed that the block teaching format challenges them to use higher order thinking skills. This enabled students to build on key concepts at the beginning of the semester and complex concepts are then developed more elaborately throughout the semester in different context whereby students develop critical thinking skills within the chemical engineering context.

80.99% of the students agreed that block teaching format reduces the amount of varied information to deal with at any one point in time. This allowed them to focus their attention on specific topics, activate prior knowledge and carry the knowledge one step higher to a new level of comprehensiveness. This may have attributed to students performing equally good even though the modules are covered in a more compact manner.

In summary, the quantitative survey result obtained from the first run of block teaching was encouraging with majority of the students either “Agree” or “Strongly Agree”, indicating strong alignment to the intended outcome.

In addition to the quantitative survey described above, a qualitative survey was also carried out using the following questions.

Question 5: What **difficulties** (if any) did you experience with the block teaching format?
Question 6: What **positive** aspects did you experience with the block teaching format?

The main issue students faced in the first run of the block teaching was the schedule of Test 1 for *Chemical Engineering Thermodynamics* [Standard 11 – Learning Assessment]. Hardly had they accustomed to the new semester, they had to take the test in Week #3. Another concern was the schedule of the module’s examination, which was held almost three months after the syllabus was covered, making the process of revision challenging. Some felt that the schedule is too intense for the first module.

To address these issues surfaced from the survey, the module team identified two areas for improvement. Firstly, adjustment was made in the teaching schedule and implemented in Academic Year 2019/2020 (second run of block teaching) as shown in Figure 2.

When Test 1 of *Chemical Engineering Thermodynamics* was scheduled on Week #4 instead of Week #3, this gave students an additional week for preparation. The module content was covered within a duration of five weeks. This was an increase of one week from the previous run of four weeks. This allowed the module content to be delivered at a slower pace that allows the students to grasp what is being taught, manage new information, translate them into useful knowledge and stay engaged.

Secondly, the modules were changed from examinable to non-examinable type. The summative assessment at the end of the module was renamed from examination to Test 2 while maintaining the rigour of the assessment. This provided the module team the liberty to schedule the test at an appropriate time during the semester. So, Test 2 of *Chemical Engineering Thermodynamics* was scheduled a few weeks after the module content had been taught to avoid a long time lapse between the completion of the module and the date of the summative assessment. The test was also scheduled on the week after the mid-semester vacation where students could use the vacation time to revise the learning material.

After the improvements were implemented for the second run of block teaching, the same quantitative and qualitative survey questionnaire was carried out to evaluate the impact of the revised implementation. The result is shown in Figure 3 (right) with a response rate of 87.9%. The responses received shows a remarkable improvement as compared to that of the first run. The percentage of “Agree” and “Strongly Agree” responses increased with an average of 13.6% based on the four questions. The revised schedule provides students with a more balance workload throughout the semester and, hence, enable them to have a better grasp of fundamental concepts. This is evident where students find the block teaching format to be “very enriching, a lot of topics taught are interlinked, and it made me apply the previous chapters more efficiently”. One of the students also responded that “I felt that it was useful as it opened my eyes to how to integrate concepts from different modules together.”

In summary, the block teaching format leverages on prior knowledge to enable students to step higher to a new level of rigour. This approach requires students to utilise and activate prior knowledge thereby strengthening the grasp of fundamentals before learning at a deeper level. Such reinforcements increase the students’ confidence and ability in solving authentic but usually complex problems.

FACULTY TEACHING COMPETENCE

Faculty members play a pivotal role in the success of the block teaching format. The improvement could be attributed to the fact that with more experience after the first run, faculty members in the module team have greater capability to effectively impart the fundamental engineering concepts in the first module and reinforce the concepts in the subsequent two modules, thereby assisted the students to connect the dots among the concepts.

To design a curriculum that is cohesive, the block teaching approach requires faculty members to collaborate and coordinate on the content to be taught across different modules, when and in which modules and at what level of complexity. Faculty members will have a good overall concept of the curriculum instead of teaching in silo that translates to higher proficiency in creating the links for students within a module and between different modules. They play an active role in explaining explicitly how the key concepts are linked from one module to another, thus providing an integrated learning experience to students. Students were motivated to learn when the faculty member presents the process and content well (Hazel Mae & Alegre, 2019). So, faculty members must have the competence to deliver technical content that spans across different areas of studies in chemical engineering, which is different from traditional practice.

In order to achieve a coherent teaching practice across the entire cohort of students, the module team leader designs the teaching and learning materials using the CDIO approach described by Cheah (2009) using case studies and various pedagogies. At the beginning of each semester, the module team leader conducts a briefing to the module team members so as to ensure everyone in the teaching team aligns to the learning outcomes and delivers an integrated learning experience to students. As the module team typically consists of more than three faculty members, delivering consistent integrated learning experience for the entire cohort of students is highly desirable but a real implementation challenge. Nonetheless, the Course Management Team encourages faculty members to maintain the openness to seek clarification and share best practices as they place students' best interests at heart.

Finally, when a faculty member teaches the same group of students across various modules in the block teaching model, this typically results in greater rapport formed between students and faculty members, which can serve as an indirect inspiration for students to perform well.

PLANS FOR MOVING FORWARD

The outcome of this study was based on the modules offered within a semester of a three-year course. Some feedback were gathered from the first cohort of students through a focus group discussion when they progressed to later years in the course. These anecdotal evidences also suggested that:

1. Interaction between lecturer and student reinforces integrated learning.
2. Block teaching provides "levelling up" for students.
3. Block teaching helps students focus on their learning.

The Course Management Team will continue to gather more tangible evidences that illustrate students deepening their understanding in the spiral curriculum, seeing relation and connection between concepts, especially in later years of studies. The team will also review the integration of critical thinking in the curriculum where Sale & Cheah (2013) described the teaching and application of critical thinking in Year 3 curriculum. However, the development of critical thinking can be facilitated through a variety of active learning strategies that systematically cue such types of thinking. So, there are opportunities for this to be taught starting in Year 1, subsequently be enhanced in Year 2 and applied in Year 3.

Survey responses indicated that block teaching and spiral curriculum benefitted students, however, there are operational challenges such as scheduling tests and managing assessment workload. These remain to be optimised by distributing the workload throughout the semester so that it is more manageable for the students so as to making learning more conducive. For example, when the final summative assessment of *Chemical Engineering Thermodynamics* was scheduled after the mid-semester vacation, some students felt that they were deprived of a proper vacation break where they had to use their vacation period to do revision and preparation for the final test. So, in Academic Year 2020/2021 (third run of block teaching), the final test will be scheduled before the vacation period so that the students do not need to do revision during mid-semester vacation. This will give students a well-deserved rest time.

In addition, to help students "gear up" after a 6-week long vacation between semesters, a Back-to-Campus activity will be introduced on the first week of Semester 2. It aims to enable students to kick start the semester effectively. The activity requires students to activate prior knowledge acquired in Semester 1 and apply it in a given scenario to solve some engineering problems. The activity provides the platform for students to activate prior knowledge and integrate the concepts learnt in Semester 1 and provides a preview of important concepts to be introduced in Semester 2. This will further enhance the spiral curriculum structure.

Lastly, this study has shown that the student performance are comparable with no significance difference in terms of mean score and pass rate. Other interacting factors could have been present but not discussed, such as student's pre-diploma educational background, learning ability, mode of lesson delivery and students' perceptions on the use of CDIO approach. These can be further investigated in future studies and build upon the current efforts to improve student performance.

CONCLUSION

In conclusion, the spiral curriculum model has benefitted student learning where key concepts and principles are revisited over time to further clarify and extend the knowledge base. This is achieved by adding new related knowledge, enhancing knowledge and skills integration and further refining them until students make sense and apply them purposefully and meaningfully. Faculty members play vital roles in teaching key concepts that are fundamental to understanding, and the need for spaced deliberate practice over time to ensure that knowledge and skills are encoded and cemented in the student's long term memory. The implementation of spiral curriculum using block teaching as a means for the DCHE curriculum has shown positive impact on student learning where suitable pedagogy arrangements are applied and supported by faculty members to facilitate learning that is of most worth to the students.

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BIOGRAPHICAL INFORMATION

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