A MODEL TO EXPLICITLY TEACH SELF-DIRECTED LEARNING TO CHEMICAL ENGINEERING STUDENTS

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ABSTRACT

The 3-year Diploma in Chemical Engineering (DCHE) curriculum had undergone a major redesign to transition to a spiral curriculum so as to better meet the learning outcomes mandated by SkillsFuture, the Singapore Government's national initiative. One of the outcomes is the development of a lifelong learning culture. In response, Singapore Polytechnic came up with several initiatives to enhance the competencies of its students, one of which is self-directed learning (SDL). This is achieved via the progressive nature of learning afforded by the spiral curriculum course structure by explicitly teaching a SDL model to students. This will be done over 4 semesters through 4 practical modules, beginning in Semester 1 of Year 1 when students first joined the polytechnic. There will be 1 practical module per semester where various learning tasks are designed to engage students to develop their knowledge, skills and attitudes as process technicians or future chemical engineers (with further studies). Using the spiral curriculum design, each concept is revisited again and again in later modules with increasing level of difficulty. It is notable that all learning tasks are designed to anchor to a typical chemical plant found in the oil and refining industry, to provide context and continuity required in a spiral curriculum. The 4 practical modules are also supported by other core chemical engineering modules within the same semester and across different semesters as part of the spiral curriculum. Using constructive alignment, students are assessed appropriately using a combination of formative and summative assessment over the 4 semesters. Preliminary findings showed that majority of students in general are receptive to the use of SDL model, but more research is needed to address the effectiveness of the SDL workshop, and improve the students' learning experience. This paper concludes with a discussion of our plans to move forward.

KEYWORDS

Chemical Engineering, Spiral Curriculum, Self-Directed Learning, CDIO Standards 1, 2, 3, 4, 7 and 11

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 as "faculty" in the universities.

INTRODUCTION

The 3-year Diploma in Chemical Engineering (DCHE) curriculum from Singapore Polytechnic (SP) had undergone a major redesign to transition to a spiral curriculum so as to better meet the learning outcomes mandated by SkillsFuture, the Singapore Government's national initiative (Cheah & Yang, 2018). The initiative was launched in 2015 aimed at helping Singapore manufacturers improve their operations to remain competitive in the global marketplace, promoting lifelong learning by providing workers with avenues to deepen their existing skills and acquire new ones, so that they can stay relevant amid ever-changing workplace demands. As an educational institution, one of our key roles is therefore preparing students to be lifelong learners. Self-directed learning (SDL) has been identified as the key approach for becoming a lifelong learner (Candy, 1991; Alexander, et al, 2004; Tunney & Bell, 2011). A meta-analytic review by Boyer et al (2014) on SDL research over 30 years, five countries, and across multiple academic disciplines provided a strong case for using SDL to promote lifelong learning skills in students. This paper shares how we use the spiral curriculum (Bruner, 1960) to explicitly teach students skills in becoming a self-directed learner.

WHAT IS SELF-DIRECTED LEARNING?

The term self-directed learning is widely attributed to Knowles (1975) who described it broadly as “a process in which individuals take the initiative, with or without the help of others, to diagnose their learning needs, formulate learning goals, identify resources for learning, select and implement learning strategies, and evaluate learning outcomes”. However, in today’s adult learning literature, it had been reported that there exist a number of terminologies related to self-directed learning such as autonomous learning, independent learning, self-managed learning, self-organized learning, self-regulated learning, self-determined learning, self-planned learning, self-initiated learning, etc (Cosnefroy & Carré, 2014). According to Carré & Cosnefroy (2011), the 2 most commonly used are self-directed learning (hereafter SDL) and self-regulated learning (hereafter SRL). As noted by Loyens, et al (2008), even scholars in educational psychology have suggested that the 2 terms be used interchangeably in the literature. This is perhaps due to the similarity of the two concepts: both aimed at describing the various dimensions of independent, agentic management of one’s learning efforts. For example, overall both SDL and SRL involve active engagement and goal-directed behaviour (Loyens, et al, 2008) and both address issues of responsibility and control in learning (Pilling-Cormick & Garrison, 2007). Saks & Leijen (2013) noted that the terms are not clearly distinguished in the literature thus leading to “tangled understandings and complications” in measuring SDL and SRL.

For this work, we adopted the position taken by Loyens, et al (2008) that SDL is considered as a broader construct encompassing SRL as a narrower and more specific one. SDL has also been treated as a broader concept in the sense of learner’s freedom to manage his learning activities and the degree of control the learner has. According to Jossberger, et al (2010), the constructs of SDL skills and SRL skills are ascribed to different levels. The SDL is suggested to be situated at the macro level, where it refers to the planning of the learning trajectory – a self-directed learner is able to decide what needs to be learned next and how his learning is best accomplished. A skilful self-directed learner diagnoses his learning needs, formulates learning goals, finds suitable resources for learning and monitors his learning activities. SRL as the micro-level concept concerns with processes within task execution. SDL may include SRL but not the opposite (Jossberger *et al,* 2010). In other words, a self-directed learner is supposed to self-regulate, but a self-regulated learner may not self-direct.

THE DCHE SPIRAL CURRICULUM MODEL

Cheah & Yang (2018) had earlier presented the work done to redesign the DCHE curriculum in response to the SkillsFuture Initiative using the CDIO approach. One of the key features of our spiral curriculum is the introduction of 4 new practical modules, one for each semester in Year 1 and Year 2. Figure 1 shows the DCHE spiral curriculum model, highlighting progressive learning in the 4 practical modules, namely *Laboratory & Process Skills 1 & 2*, and *Process Operations Skills 1 & 2*. For each module, various learning tasks are designed using CDIO to engage students in learning how process technicians and chemical engineers work in the real world (Standard 1). Using the spiral curriculum design, each concept is revisited again and again in later lessons with increasing level of difficulty (Standard 2). The hands-on activities in each practical module are supported with key concepts covered in core modules within the same semester of study. All learning tasks are anchored to a typical chemical plant found in the oil and refining industry, to provide context, and continuity in competency build-up required in a spiral curriculum (Standard 3).

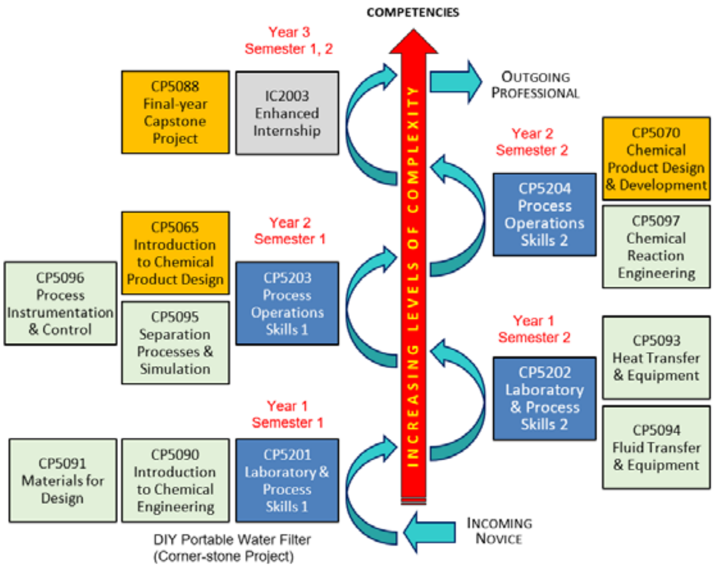


Figure 1. The DCHE Spiral Curriculum Model

Key CDIO skills such as teamwork, communication, critical thinking, hypothesis testing, etc are explicitly covered in the 4 practical modules (Standard 7). In the same vein, SDL will be deliberately taught to students, starting in Year 1. Here students will be introduced to a SDL model, with the necessary tools and scaffolding (Ley, et al, 2010), with feedback (Embo, et al, 2010) provided to help them use the model and monitor their learning metacognitively. Later in Year 2, the scaffolds will be gradually removed, and students are expected to be able to use the model without explicitly being told to do so. Students are also required to be able to transfer the skills acquired to new learning tasks, and to new contexts, especially during their final-year capstone project. This approach is consistent with that advocated by McCauley & McClelland (2004), who called for the teaching of SDL be included throughout the whole course.

THE DCHE-SDL MODEL

Although there are several models of SDL available in the literature, such as the 4-Stage Self-Directed Learning Model (Grow, 1991), Personal Responsibility Orientation (PRO) Model (Brockett & Hiemstra, 1991; Heimstra & Brockett, 2012) and the Comprehensive Model of Self-directed Learning (Garrison, 1997), Cycle of Self-directed Learning (Ambrose, et al, 2010), SP management had decided to formulate its own SDL model for adoption by the courses. In DCHE, we therefore use the SDL model (see Figure 2, left side) so that it can be *explicitly taught* to our students. In a nutshell, the model is built on students having a growth mindset and intrinsic motivation to learn on their own, as well as being able to metacognitively reflect on their learning process.

It is important to note here that we are not advocating the preferred use of our model over the existing ones, as we are not making comparisons over the relative advantages or disadvantages of the different models. What we are emphasizing in this paper is how it is being implemented using the CDIO approach, making reference to applicable CDIO Standard(s) as appropriate. The desired outcome is we hope to see is that students are able to transfer their learning from one context to another, as shown by the large arrow (Figure 2, left side). The subsequent section will address our experience with the model to-date.

Growth mindset (Dweck, 2006) refers to the belief that intelligence can be developed. Students with a growth mindset understand they can get smarter through hard work, use of effective strategies, and help from others when needed. It is contrasted with a fixed mindset where the belief that intelligence is a fixed trait that is set in stone at birth. Research has shown that educating students about the growth mindset and how they can improve their learning experience is a key step towards increased intrinsic motivation (Ng, 2018; Colouri, 2014).

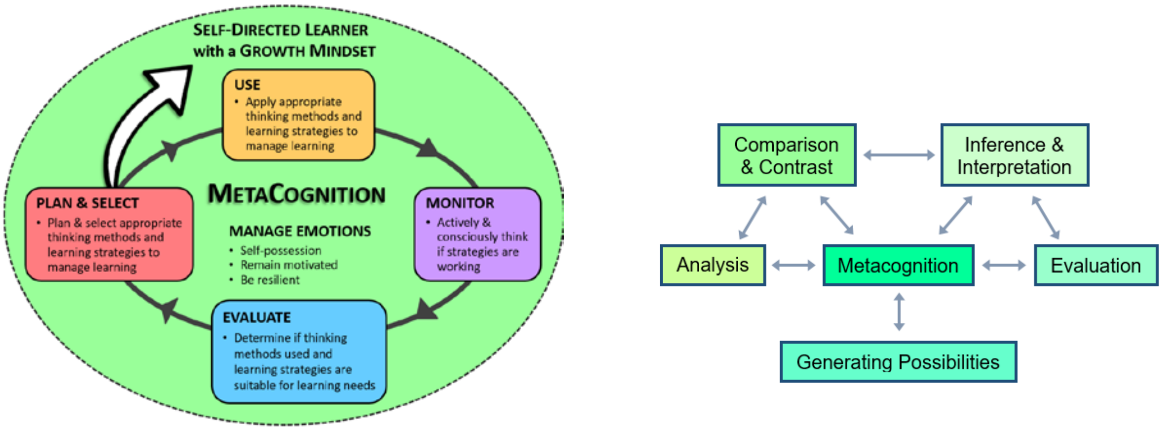


Figure 2. DCHE SDL Model (left) supported by Sale's Model of Thinking (right)

Metacognition (Schraw, 1998) refers to the awareness and understanding of one's own thought processes. Being metacognitive means to be aware of one's thinking, emotion/feeling and behaviour, evaluating how well one is using the range of specific thinking skills, and taking necessary corrective action to plan, monitor, and assess one's learning process and performance. Metacognition can therefore nurture students' learning and self-awareness of the learning process, as well as facilitate the transfer of understanding across disciplines. Metacognition can be taught through deliberately designed activities (Mills, 2016; Veenman, et al, 2006). We also introduce the use of reflective practice in learning so that students can reflect on their learning in order to discover new insights and a more sophisticated understanding (Kaplan, et al, 2013). We also require students to acknowledge the roles played by one's emotions in influencing the learning process (Bower, 1992; Rager, 2009) when they reflect on their own learning experience. Lastly, we leveraged on Sale's Model of Thinking (Sale & Cheah, 2011) to support the development of metacognition (Figure 2, right side). We explicitly teach students to discern between the different thinking heuristics so that they become aware of such "language of thinking" when we facilitate the learning in class, including modelling the thinking process in developing metacognitive competency. The 2-headed arrows indicate that mutually supportive nature of each thinking heuristic, with different combinations of which are often used simultaneously.

IMPLEMENTATION OF THE DCHE SDL MODEL

We start by introducing students to the growth mindset in Year 1 Semester 1 (i.e. Stage 1A) in an activity in the practical module *Laboratory & Process Skills 1* (Figure 4) where they are tasked to produce a prototype portable water filter kit using limited resources. Students are encouraged to go ahead and built a prototype without having first learnt about the engineering principles behind water filtration. This activity constitutes the DCHE corner-stone design-built experience for students in the *Introduction to Chemical Engineering* module (Standard 4).

The Model of Thinking and DCHE-SDL Model are next taught in Year 1 Semester 2 (i.e. Stage 1B), via a series of 3 workshops (P04 to P06 in Figure 4, conducted sequentially) in the practical module *Laboratory & Process Skills 2*. Students need to complete 3 practicals (P01 to P03) in the module prior to attending the workshops. These practicals are similar to those that students had done in *Laboratory & Process Skills 1*, but with a higher level of difficulty. Growth mindset is also reinforced these 3 practicals where students are required to come up with their own experimental procedures to carry out various scientific investigations as part of acquiring laboratory skills such as experimentation, investigation and knowledge discovery (SP-CDIO Syllabus Part 2.2, not included in this paper).

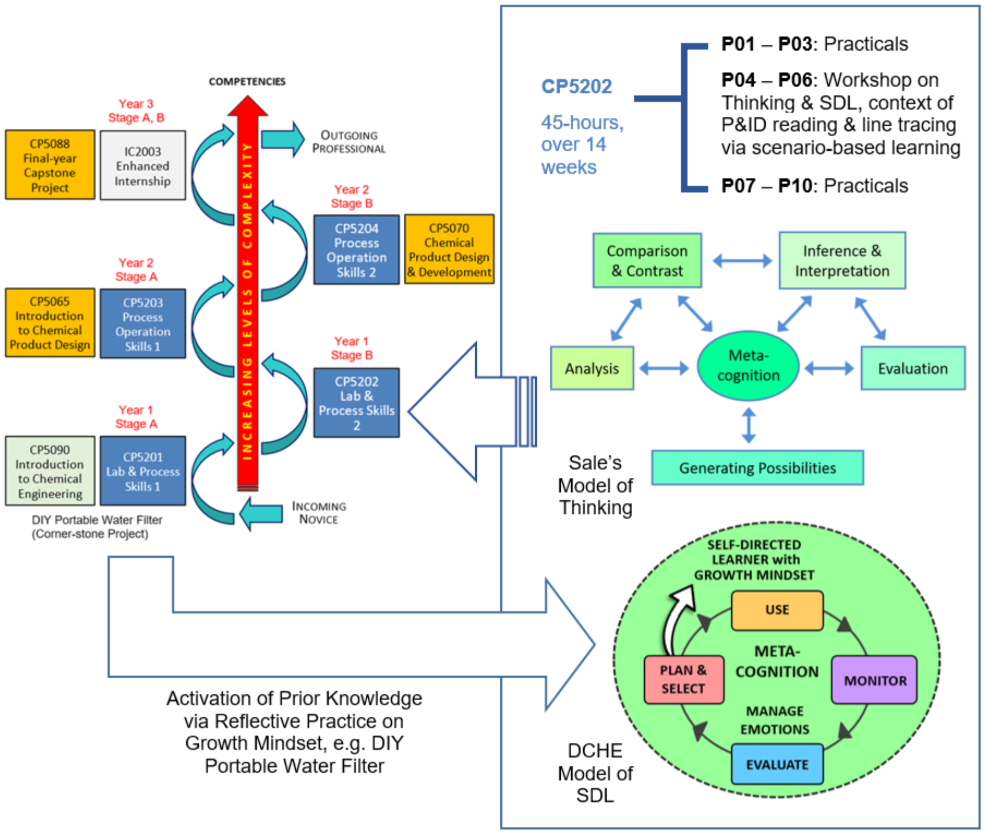


Figure 4. Integrating SDL into DCHE Spiral Curriculum

The first workshop starts (P04) with the rationale of why SDL is needed and how students can benefit from it, followed by Sale's Model of Thinking, using the corner-stone portable water filter project to demonstrate the various thinking processes employed in the building, testing and evaluating of the portable water filter. The workshop then introduces the SDL model, using the 3 practicals that students completed prior to the workshop, to bring out key challenges faced during their conduct of these practicals. The first 2 authors, serving as facilitators, demonstrate to students how a self-directed learner manages his/her own learning when addressing the challenges. Students are then asked to reflect on their own learning experiences for these practicals and are given the opportunity to resubmit their work.

The next 2 workshops (P05 and P06) then focused on getting students to apply the Model of Thinking and SDL model via various learning tasks designed to develop core competencies in chemical engineering, namely P&ID (piping and instrumentation diagram) reading and line tracing. Various thinking processes (including metacognition) and skills in SDL are explicitly taught in the context of developing these core competencies. Workshops are interactive in nature, with small group discussions to respond to scenarios presented. Some scenarios require students to obtain additional information on their own, and the lecturers (as facilitators) guide students in the discussion, and reinforce the practices of a self-directed learner, e.g.

explaining what can one do to monitor his/her own learning progress. The in-class activities are intentionally designed to be incomplete, and students are required to complete their own learning after class, using the SDL model. Students also get the opportunity to carry out line-tracing and sketch their own P&IDs from scratch, for selected pilot plants in the workshop. These P&IDs will be used for the remaining practicals (P07 to P10) in the modules. Lastly, students are required to reflect on their learning experience by submitting reflection journals. These journals are marked, commented on and returned to students. They are part of the formative assessment process, hence not graded (Standard 11).

As shown in Figure 4, there will be a continuation in the integration of SDL beyond the introduction in *Laboratory & Process Skills 2* in Stage 1B. Students will be expected to transfer these skills to more challenging process skills to further enhancing the core competencies next academic year, namely in *Process Operations Skills 1 & 2*, in Year 2 Semester 1 (i.e. Stage 2A) and Semester 2 (i.e. Stage 2B) respectively. In addition, students are also expected to use the SDL skills to manage their own learning in 2 chemical product design modules, one in each semester in Year 2 (*Introduction to Chemical Product Design*, *Chemical Product Design & Development*). The latter will be interesting as the context for which the SDL skills are applied will be quite different – namely in terms of skills in conceiving, designing, implementing and operating a chemical product, service or system. Lastly in Year 3, students are expected to be able to transfer (Scharff, et al, 2017) their SDL skills gained and apply to new challenges presented in the *Final-Year Capstone Project* and *Enhanced Internship* program.

PRELIMINARY EVALUATION TO DATE

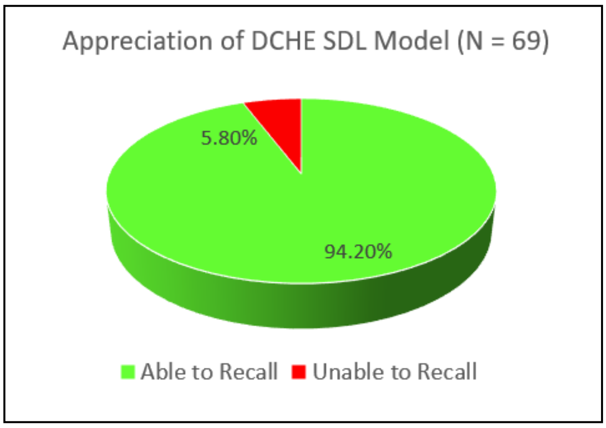
We carried out a short survey in December 2018 to obtain a "feel" of the students' experience with the approach thus far. At the time of this submission, we are still analysing the results. For the purpose of this paper, the following are some of the questions posed:

A. Name one or more parts of the Self-Directed Learning Model you remember.
B. Did the workshops for P05 and P06 help you to appreciate the use of the Self-Directed Learning Model in gaining new knowledge? Why?
C. Which one of the following best describes your learning experience with the Self-Directed Learning Model so far?

Questions A and B are open-ended. For Question C, students are required to select 1 of 8 responses from a drop-down list, comprising the following:

- It helps me to work out how to learn in a systematic manner
- It is useful when I need to learn something new/ complex
- I am not too sure yet as I do not have sufficient practice using it at this moment in time
- I think only some parts of it are useful to me
- It is too complex to make use of
- I do not see how it can be applied
- I have my own way of learning, which I think is good enough for me
- I do not see its relevance in helping me learn

The survey was administered to all 7 classes of Year 1 DCHE students who took the module, totalling 130. A total of 81 responses were received. However, some responses were not accepted as they are deemed invalid. For example, for Question A, some students provided key competencies of chemical engineers (such as to conduct line tracing, sketching P&IDs) which were technical learning outcomes from the workshops. Likewise, some students left the field blank (i.e. unanswered, as we do not design the survey to require respondents to answer a question before they can proceed to the next question), and these too are deemed invalid. As such, the number of respondents to each question can vary. The findings relevant to these questions are presented below in Figures 5 to 7.



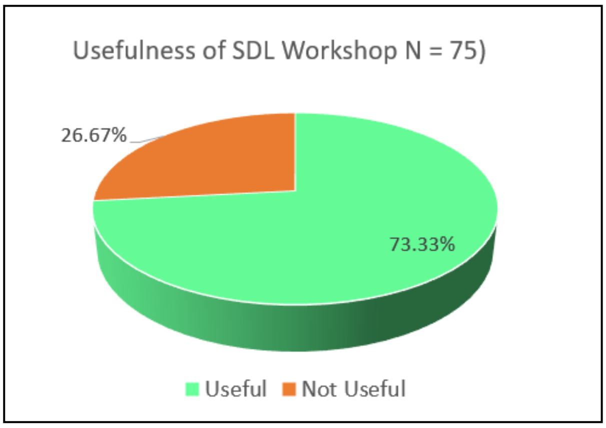


Figure 5. Responses to Question A

Figure 6. Responses to Question B

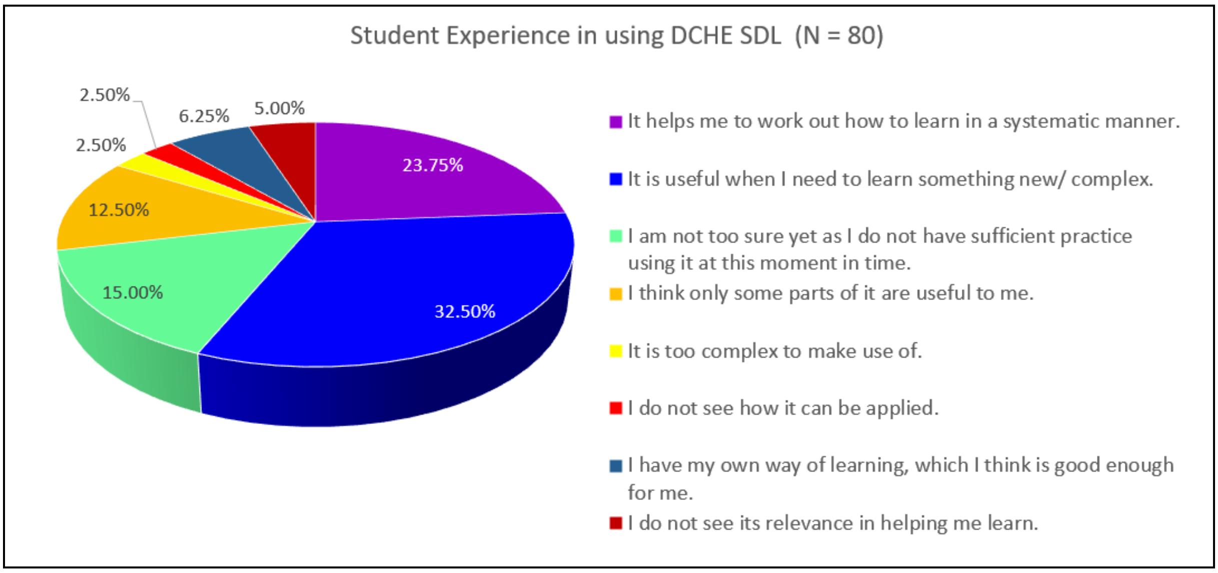


Figure 7. Responses to Question C

For the first run of this initiative, it can be seen from Figure 5 (with 69 valid responses) that the majority of students are able to relate to the use of the SDL model. In general, students are able to identify with the key steps in being a self-directed learner, and quite a number are able to mention metacognition as an important factor. However, despite the high positive responses, only about 73% of respondents found the 3 workshops useful (Figure 6, with 75 valid respondents). This may be due to the opinions of some students who are still ambivalent about the importance of SDL as shown in Figure 7 (with 80 respondents). Only about 56% of students reported understanding the potential benefits of SDL, while about 16% do not think so: this is made up of 2.50% who thought that it was too complicated, another 2.50% who had no idea how to apply it, 6.25% who felt that their own way of learning is superior, and 5.00% who reported seeing no relevance of SDL in helping their learning.

Some of the negative responses may represent the current state of the students' perception of SDL, characterised by that of confusion, frustration, and dissatisfaction (Lunyk-Child et al, 2001). This is not a surprise, given that it is the first time our students are exposed to SDL. It could be worthwhile finding out students' perceived ability to learn on their own, which may have been built on learning strategies used during their secondary school days and require adjustment to match the needs of tertiary education. Some students are uncomfortable with the approach, as they expect that in a formal education setting (such as the 3 workshops) their learning should still very much be "directed" by the lecturers, similar to that in Secondary Schools. Part of their perceived inability to use SDL may stem from what Butcher & Sumner (2011) termed as the "sense-making paradox" where students are required to employ deep-level thinking skills, but often lack the knowledge needed to deeply analyse information and successfully integrate it with their own existing knowledge. Some of the differences in students' attitude and perceptions toward SDL can also be due to different facilitation styles by the teaching team. The first 2 authors are involved in teaching of 3 out of a total of 7 classes. Also, due to other timetabling requirements, students in each class are not of the same academic capabilities. Response rates from the different classes are also different. These factors make it challenging to understand at a deeper level how receptive each student is to the explicit teaching of SDL. Lastly, this being the first run of the module, we are not able to make a comparison between students' learning results before and after applying SDL.

MOVING AHEAD

We will continue to analyse the survey findings and cross-reference other documents such as reflective journals and in-course assignment submitted by students as part of course work to gain further insights on their learning experience. At the point of submission of this paper, it is fair to say that we had barely scratched the surface of SDL. Much has been said in the published literature about SDL. Suffice to say, this topic still attracts a lot of attention, perhaps due to its elusive qualities which defy precise definition (Hewitt-Taylor, 2001; Grow, 1991). Levett-Jones (2005) noted that the introduction of SDL into a curriculum has not always been successful. It will be worthwhile for us to delve into available research to better understand the various findings on SDL, including student perceptions and perspectives (e.g. Douglass & Morris, 2014), teacher belief (e.g. Heimstra, 2013), learning environment and pedagogy (e.g. Ryan, 1993), just to name a few areas, as we continue to work on developing our students' skills in SDL.

Moving ahead, our students will take up modules related to chemical product design in Year 2 (Figure 4). The usefulness of project-based learning to teach students SDL skills have been reported in the literature (e.g. Eggermont, et al, 2015; Johnson, et al, 2015). Hence, we will work closely with the teaching team of *Introduction to Chemical Product Design* (Year 2, Semester 1) and *Chemical Product Design & Development* (Year 2, Semester 2) to continue to improve our students' SDL skills. We will also consider measuring the students' readiness for SDL through instruments such as Self-Directed Learning Readiness Scale (Guglielmino, 1977), Oddi (1986) and Gibbons (2002). Survey results using these instruments can help us pinpoint areas in SDL where students are weak in and design appropriate learning tasks. We are also interested in finding out if students are able to improve their SDL skills as they progressed through the spiral curriculum. In this regard, we are reminded of the works of Litzinger, et al (2003) as well as that of Francis & Flanigan (2012); whose research showed that SDL is not directly related to students' academic standing. This may also be an area worthy of further research as we track the students' progress over the 3 years of study.

Students' SDL skills development will come a full circle when they reach Year 3, when they will complete a capstone project and an internship program. This is where they need to transfer their SDL skills developed over the last 2 years into new applications. Stewart (2007) had shown that SDL readiness was a key enabler for achieving learning outcomes from project-based learning, which are often open-ended, ambiguous and requires knowledge beyond what had been covered in the curriculum. Other outcomes may include desired graduate attributes such as ethical reasoning, cross-cultural awareness, etc. As for the internship, students will be placed in a work environment that may involve tasks that are ambiguous and far-separated from their prior experience. Thus they must be able to adapt quickly, and this adaptation requires development of self-directed learning skills.

CONCLUSION

This paper shares the approach taken by the authors to integrate self-directed learning into a chemical engineering curriculum using the CDIO approach. Based on the preliminary findings, it would appear that it is useful to explicitly teach students the importance of self-directed learning and provide them with a model of how to do so. Also, it seems that engaging students early (specifically, in this case, right from Year 1) is a wise decision to take, even though the results showed clearly that more could be done to improve their learning experience, such as improving the workshop design for a start. However, as noted by Silen & Uhlin (2008), students need challenges, support and feedback in their struggle to become self-directed learners and thus require ongoing attention from lecturers. This is an area where training in facilitation will be useful for the teaching team. We will also continue to work with other lecturers to continue developing our students' SDL skills as they progress through the spiral curriculum; as well as engaging in other research into SDL. Future papers will share more work done in this area.

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