# CASE STUDY ON SELF-DIRECTED LEARNING IN YEAR 1 CHEMICAL ENGINEERING

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## ABSTRACT

This paper provides a case study on how the Diploma in Chemical Engineering (DCHE) integrates self-directed learning (SDL) into its 3-year curriculum using the CDIO Framework. The paper first provides a brief overview of the DCHE spiral curriculum and our SDL model; and how we aim to progressively develop this competency in our students by explicitly teaching of SDL skills. The paper then presents details of how we integrate SDL into core modules, starting with answering with the questions: (a) The full set of knowledge, skills, and attitudes that engineering students should possess as they leave the university, and the required level of proficiency, and (b) The way that we can do to ensure better that students learn these skills. The paper thereafter shares how we define the desired learning outcomes and proficiency level for SDL. For the former, we refer to the SP-customized CDIO syllabus for the underpinning knowledge of what constitutes SDL in general, as well as the Technical Skills and Competencies of the Energy and Chemicals Skills Framework (E&C SF) of the Singapore SkillsFuture Initiative to provide the technical knowledge and context of SDL in the practice of chemical engineering. For the latter, we refer to the Generic Skills and Competencies of the E&C SF. The paper then shares the design of learning tasks in the Year 1 Semester 2 module *Laboratory and Process Skills 2*, with examples of real-world job roles and the responsibility of a chemical process technician or technologist in the chemical processing industries. The paper also shares our efforts of providing scaffolds and online guidance questions to help students in their learning, and use of reflection journal to evaluate if they had developed the required competencies. Lastly, the paper shares results of our survey of the students' learning experiences in their SDL journey and possible areas of improvement. (304 words)

## KEYWORDS

Chemical Engineering, Spiral Curriculum, Self-Directed Learning, CDIO, Standards 1, 2, 3, 6, 7, 11

<u>NOTE</u>: 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 university contexts are often called "courses." A teaching academic is known as a "lecturer," which is commonly referred to as "faculty" in the universities.

## INTRODUCTION

In an earlier paper, Cheah et al. (2019) shared the general approach taken by the Diploma in Chemical Engineering (DCHE) to integrate self-directed learning (SDL) into its 3-year course which is structured around a spiral curriculum (Cheah & Yang, 2018) as shown in Figure 1. The earlier paper shared how SDL was introduced into the Year 1, Semester 2 core module entitled *Laboratory and Process Skills 2*. This paper shared specific activities in the module to illustrate how CDIO is used and provide an update to the experience gained from the module redesign process.

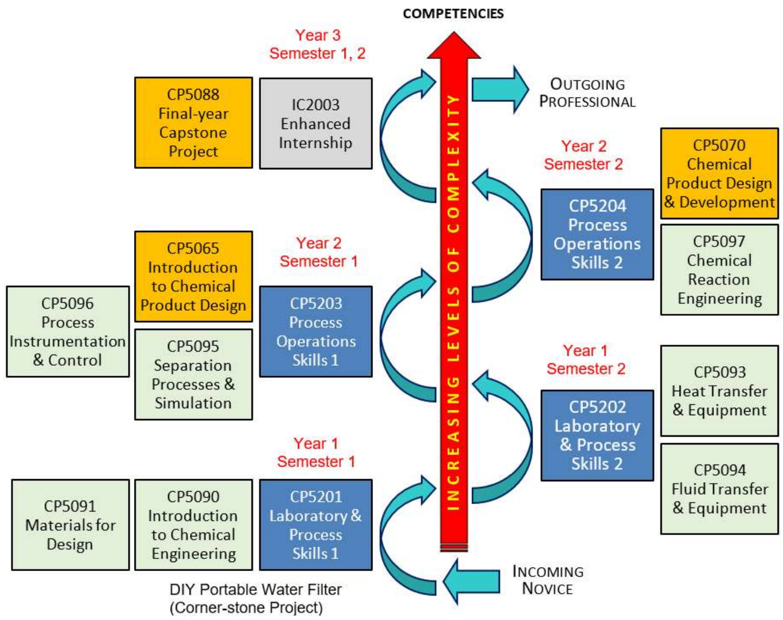


Figure 1. Integrating SDL into DCHE Spiral Curriculum

The inclusion of SDL into the integrated curriculum (CDIO Standard 3) involves the explicit teaching of key steps in becoming a self-directed learner using the model, as shown in Figure 2, which also includes the teaching of good thinking heuristics (Cheah et al., 2019).

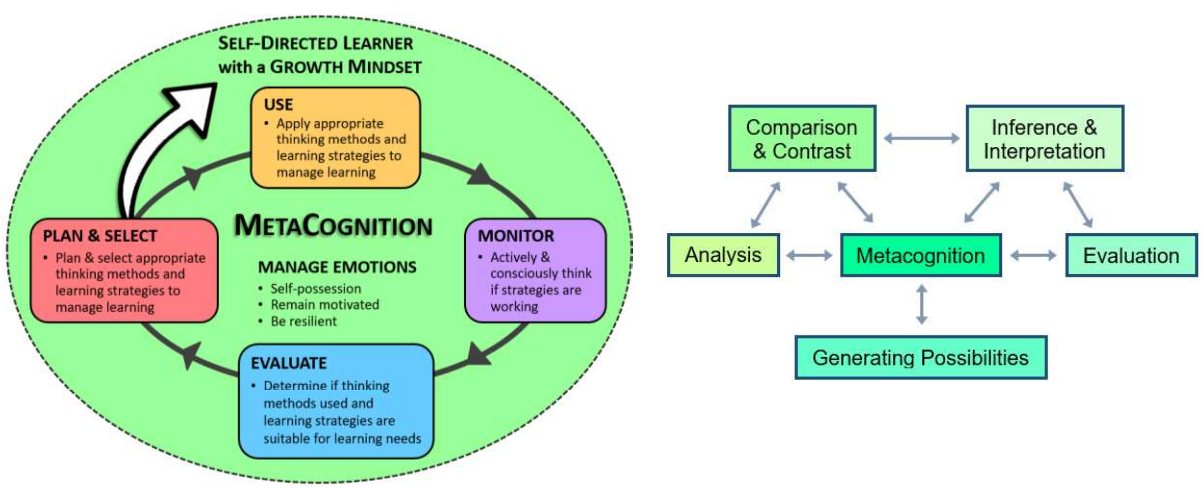


Figure 2. DCHE SDL Model (left) supported by Sale's Model of Thinking (right)

## THE CDIO DESIGN APPROACH TO INTEGRATE SDL SKILLS IN CURRICULUM

Using the CDIO approach, we seek to answer the following questions posed by Crawley et al. (2007):

- What is the full set of knowledge, skills, and attitudes that engineering students should possess as they leave the university, and at what level of proficiency?
- How can we do better at ensuring that students learn these skills?

We first unpacked the notion of SDL by taking reference from the SP-customized CDIO syllabus, in particular, section 2.4.6 which showed the underpinning knowledge for what constitutes SDL:

Engage in Lifelong Learning (Self-directed Learning)

*Identify key aspects of the learning process*

*Explain how emotions and beliefs affect learning*

*Explain the motivation for lifelong learning, e.g., curiosity, professional development, etc*

*Appraise one's own learning needs*

*Identify strategies and skills for lifelong learning*

*Use a range of learning strategies and skills (e.g., goal setting, learning plans, managing information, receiving feedback, etc.)*

*Evaluate competence attainment in terms of goal(s) set and strategies employed*

In terms of proficiency level in SDL, we find it more convenient to refer to the Generic Skills and Competencies (GSC) spelled out in the Singapore SkillsFuture Initiative (Cheah, 2018), which is valid for all industry sectors in the country. There are altogether 18 GSCs, and each contains 3 levels of proficiency, namely Basic, Intermediate and Advanced. The specific GSC for lifelong learning, which is defined as: "*Seek out opportunities to enhance one's knowledge and skills. Access and acquire new knowledge and skills actively for continual learning*." Its 3 levels are as shown below:

- Basic: Organise and manage their learning by setting learning targets. Identify learning approaches to achieve work or career goals.
- Intermediate: Engage in collaborative learning by discussing one's learning with others and soliciting feedback to improve oneself continually.
- Advanced: Conduct self-reflective practices to review one's learning to facilitate continual growth in one's career or profession.

For our students, we aim to develop our students' SDL competency up to the Advanced level, in line with the aspiration of the SkillsFuture Initiative as well as the institution's new educational model currently under development. The acquisition of SDL competency is to take place simultaneously with the application of technical know-how (CDIO Standard 3) from the Energy & Chemicals Skills Framework. This will be elaborated later. The module *Laboratory and Process Skills 2* is a 45-hr module, taught over 1 semester, i.e., 15 weeks. The schedule is shown in Figure 3. In Week 1, we provide a recap of what they had learned in an earlier module, *Laboratory and Process Skills 1* in the previous semester, and the explicit teaching of the SDL model and the model of thinking (Figure 2). The first 3 activities (on Weeks 2 to 4) is a continuation of laboratory skills from another module, where students are required to use SDL in the 3 activities. This is followed by debriefing on Week 5 on what had been covered up to that point. The debrief also marked the conclusion of laboratory skills for students, where they will subsequently move on to develop capability in process skills – skills used by chemical engineers, technologists, and technicians in the operation of chemical plants.

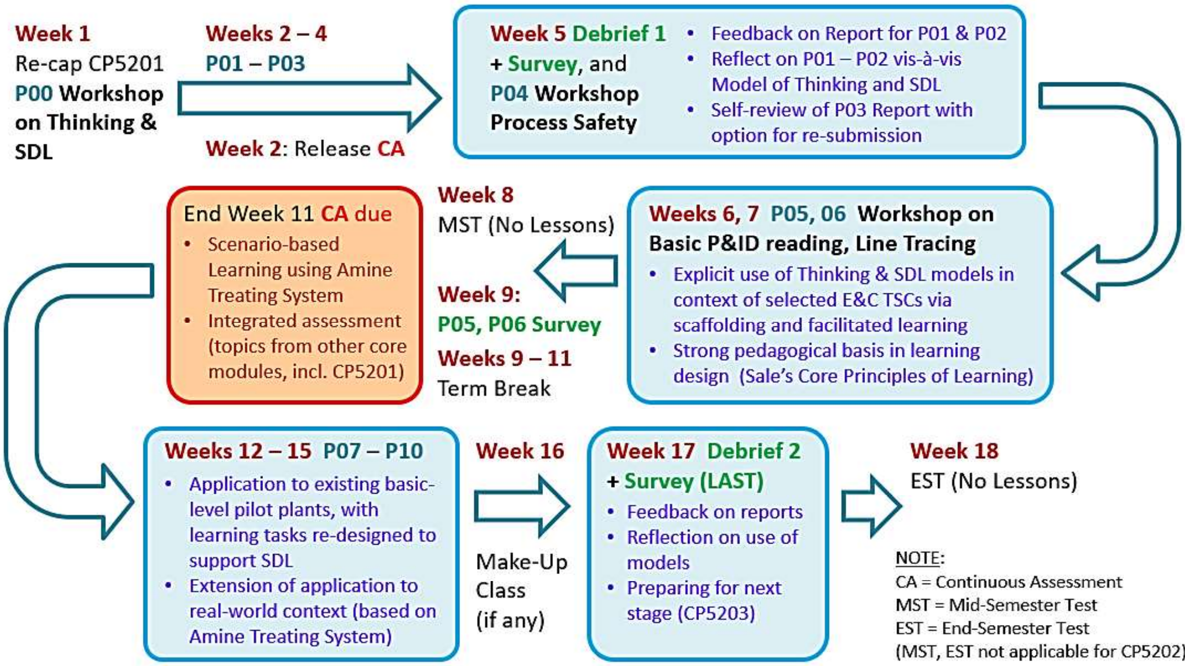


Figure 3. Development of SDL Competency in *Laboratory & Process Skills 2*

## DESIGN OF LEARNING TASKS TO SUPPORT SDL COMPETENCY DEVELOPMENT

The specific learning tasks described here took place on Weeks 6 and 7, where students learned about job roles and key tasks required of Process Technicians and Senior Process Technicians in the chemical processing industry through two "workshops" with integrated learning experiences (CDIO Standard 7). These "workshops" (shown as P05 and P06 in Figure 3) are aimed at helping students to acquire key competencies in reading piping and instrumentation diagrams (P&IDs) and carry out line tracing for the pilot plants that they will later operate on in Weeks 12 to 15. A set of P&IDs are essentially the blueprint of a chemical plant, and one can "walk the plant" using a technique called line tracing. The technical aspects of P&ID reading and line tracing are aligned to the Skills Framework for the Energy and Chemicals Sector (or E&C SF in short). More specifically, we take reference from the Technical Skills & Competencies (TSCs) for the track "Production and Process Engineering," which best meets the career pathway for our graduates, i.e., starting with Process Technician. There are many TSCs within this track, as shown in Table 1, and many are amenable to be used in the teaching of SDL. As our intention is to teach SDL from Year 1, we choose the TSC for "Engineering Drawing Interpretation and Management" to provide the context of learning (CDIO Standard 1) and learning outcomes to be achieved (CDIO Standard 2). Also noteworthy is TSC proficiency level, which ranges from 1 to 6 that matches the job role (for details see Appendix 1). For our students, we select the TSC "Engineering Drawing Interpretation and Management" and pegged the proficiency at level 2 for Process Technician, and up to level 3 for Senior Process Technician as they progressed under the spiral curriculum course design.

(a) Interpret piping and instrumentation diagram (P&ID) of a given process.

- Able to apply prior knowledge in Block Flow Diagram (BFD) and Process Flow Diagram (PFD), to explain the operation of a chemical plant using its Process Description
- Able to explain simple Process Control Loops shown in a PFD and the relationship between process variables
- Able to understand symbols shown in a Piping & Instrumentation Diagram (P&ID) in terms of the item (equipment, instrument, valves, and other piping elements) that the symbol represents and how it is connected to other items
- Able to explain information (size, class, material, etc.) contained in a line number as explained in the P&ID's Lead Sheet

(b) Perform line tracing of pilot plants.

- Able to trace a given line (process or utility), locate and identify all items (equipment, instrument, valves, and other piping elements) contained in the given line using the P&ID
- Produce a PI&D sketch (including lead sheets) of a given pilot plant
- Able to obtain additional details about an Item from various sources, e.g., nameplate attached to the item, information stamped on the item, tags, or labels secured to the item, as well as data sheets and vendor catalogs.

Table 1. Skill Map for E&C SF for the Track "Production and Process Engineering"

| Skill Map for E&C SF for the Track "Production and Process Engineering" | | | | |
|---|---|---|---|---|
| Technical Skills & Competencies for the Category "Process Operations Management" | Job Role and Proficiency Level (1 to 6) | | | |
| | Process Technician | Senior Process Technician | Production Supervisor | Superintendent |
| Control Room Operations Management | | 3 | 4 | |
| Engineering Drawing Interpretation and Management | 2 | 3 | 3 | 4 |
| Feedstock and Product Transfer Operation Management | 2 | 3 | 4 | 5 |
| Operations Reporting Protocol Application | 2 | 3 | 4 | 5 |
| Process Equipment Preparation for Mechanical Work | 2 | 3 | 4 | 4 |
| Process Operations Troubleshooting | 2 | 3 | 4 | 5 |
| Process Plant and Equipment Integrity Management | | | | 3 |
| Process Units and Utilities Operations Management | 2 | 3 | 4 | 5 |
| Standard Operating Procedures (SOPs) Development and Implementation | 2 | 3 | 4 | 5 |

Students were taken through the nuances of P&ID reading in an interactive manner, starting with pictures of various equipment, valves, pipes, and piping components and instruments. Then selected symbols that represent these items, letters representing their functions, and labels that indicate their relative positions are introduced. The students are required to prepare a document called the Lead Sheets that summarizes all this information, which is usually made available in the front part of the set of P&IDs. More specifically, they were taught P&ID symbols for valves, pipes and piping components, and instruments. They need to complete their Lead Sheets for the remainder of the items, namely equipment, which comprises various pressure vessels, columns, towers, heat transfer equipment, and fluid moving equipment. The challenges they faced are real: even though international standards exist for P&ID symbols, there are a plethora of symbols being used, from a chemical company's in-house engineering division; a vendor who markets valves and instruments, a contractor who offers EPC (engineering, procurement, and construction) services, and P&ID software vendors. Students are required to look for different symbols (from different sources) for the same item, as well as resolving any conflicting symbols (same symbols used for different items) or correcting symbols that were miscategorized. They were then given sets of P&ID drawings for the pilot plants in our workshop (CDIO Standard 6). These pilot plants were supplied by different contractors and suffered from the shortcomings mentioned above. In addition, the part of these drawings also did not reflect actual set-up as the pilot plant were relocated from older laboratories and some re-piping need to be done. The students' task is to use these drawings to do line tracing and sketch new, corrected drawings using the Lead Sheets that they prepared. As part of the deliverables (CDIO Standard 11), they need to submit these drawings for markings, and also to complete short assignments on how they managed their learning and reflections on the use of the self-directed learning model.

## FINDINGS FROM STUDENTS' LEARNING EXPERIENCE

This part reports on the finding for the second run of the learning task, with several improvements made based on results of the first run, which was reported earlier by Cheah et al. (2019). More specifically, the following are the changes made to the teaching of SDL, and the support provided for P&ID reading and line tracing:

(1) Teach SDL explicitly on Week 1 – by comparison, SDL was only taught to students for the first run during Week 5.
(2) Provide guidance questions for different stages of SDL in the context of P&ID reading and line tracing as shown in Table 2
(3) Provide samples of poor P&ID Lead Sheets and reflection journals from the first run
(4) Provide facilitation guide on P&ID reading and line tracing to the teaching team

Table 2. Guidance Questions for SDL in P&ID Reading and Line-tracing

| Stages of SDL | Guiding Questions |
|---|---|
| Plan & Select | Draft a PLAN and strategy to achieve your GOAL, e.g., should you do research in the library or use the Internet? Do you know which section in the library to go to, which category to look for, textbook or journals, etc.; If you use the Internet, possible questions include: Which web sites should I search – academic, government, companies, or vendors? How do I learn best? Make my notes, highlighting important paragraphs, or use Post-It notes? How do I cross-check my understanding? |
| Apply & Use | Are you consciously referring to the learning objectives? Is the information found comprehensive enough? Are you getting the right information? Are these particular Wikipedia entries reliable? Should I Google with something general, e.g., "P&ID," or should I use more specific keywords? How to select among the more than 1,000,000 hits? Are you also consciously tracking your learning strategy – did you ended up deviating, such as resorting to merely memorize things? |
| Monitor | How are you doing with the selected approach? How comprehensive is one source? What if you found out that different sources show different results for the same item (e.g., plate heat exchanger shown with 2 different symbols from 2 different web sites)? Will you gave up on this source and looked elsewhere? But where? What about the strategy you used – do you think it is working, e.g., did highlighting work for you? Are you overwhelmed by too many highlights? Was looking at academic writings adequate? |
| Evaluate | How satisfied are you with what you had found? Is there any nagging feeling that you may have missed something? Did you share this with your team members? What is the response? Are there any areas that you would have done differently? What is stopping you from trying out a different approach? Are you inhibited by negative emotion, fear of being rejected? From what you had obtained, are there any new areas or related topics that you discovered that you think you should explore? Why or why not? Should you use the same strategies? |

| | |
|---|---|
| Meta-cognition | Does your previous strategy (where you searched for P&ID symbols for valves as part of Pre-Class Preparation for today) work? If not, why not? Any part of the strategy that worked? Or not work, and why did it not work? How can you adapt/modify it? How about your learning approach, did that worked? Are there any 'interferences' that got in the way, e.g., Your belief ("What is published must be right"), the pressure to conform to group norm – align your view with members? Others? |
| Manage Emotion | How are you feeling, especially you could not quite get what you are looking for, after visiting several websites? Were there disagreements among members over strategy used? What measures did you take to keep your unhappiness in check –grab a cold drink? Paused and listen to music for several minutes? Others? What do you do to bring yourself back to the search again, e.g., self-vocalization? Look at the inspirational poster on the room wall? Others? |

For the second run, we collected information regarding students' learning experience from various sources: survey questionnaire, work done and focus group discussions. The last item was administered by an independent third party without the presence of the author. The main findings are shown in Figure 4 and Figure 5.

Figure 4 is based on the written response in a survey questionnaire where students reported on how the P&ID Reading and Line Tracing Activity can be of use to them when they start their first job as a junior process technician in the chemical processing industry. A comparison is made between students in the two runs. The number of respondents is comparable: 82 valid responses for the second run and 74 valid responses for the first run. The results clearly showed an increase in the number of students who found the 2 "workshops" useful.

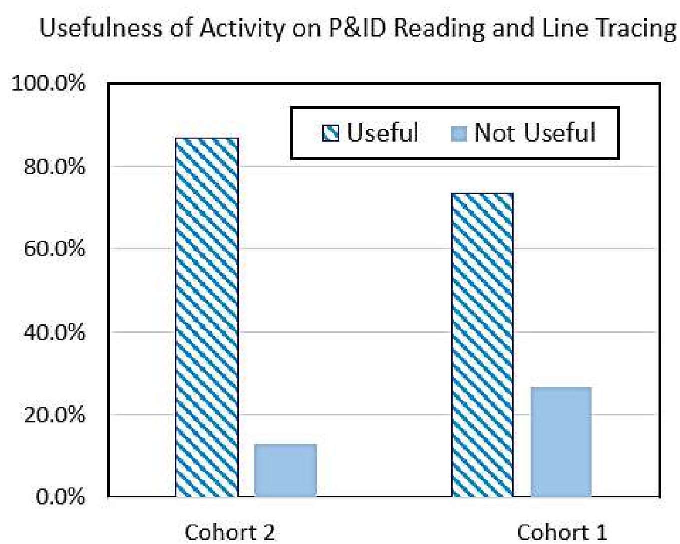


Figure 4. The usefulness of P&ID Reading and Line Tracing Activity

Figure 5 makes a comparison in responses between students in the current second run and those in the first run on how likely are they going to make use of the skill learned in subsequent activities in weeks 12 to 15, as shown in Figure 3. There are again more students who expressed enthusiasm in using the SDL model and competency gained in subsequent activities.

The results showed that there is an improvement in student learning in carrying out P&ID reading and line tracing. This showed that the various interventions introduced into the second run are working, as we also see improvements in the works students submitted. They were able to explain their experience with the SDL model better, and articulated clearly the importance of P&ID reading and line tracing for the following activities that they will embark on, as well as in the context of their future job role as junior process technicians. Sample entry from a student noted that: "*From P05 and P06, we learned many important ways to do line-tracing and how to read P&ID. These skills will be very important for future practicals. For example, when we are doing line-tracing, we must know where to start. For example, the shell-and-tube heat exchanger, we can start from the liquid in the storage tank and slowly trace the whole system from the start to the end. This will give us a clearer picture of the whole system and understand how to identify the different pipes, valves, and different components in the heat exchanger, and we will also learn how to draw and identify the different parts of any P&ID in the near future. Hence, P05 and P06 are useful, educational, and beneficial*."

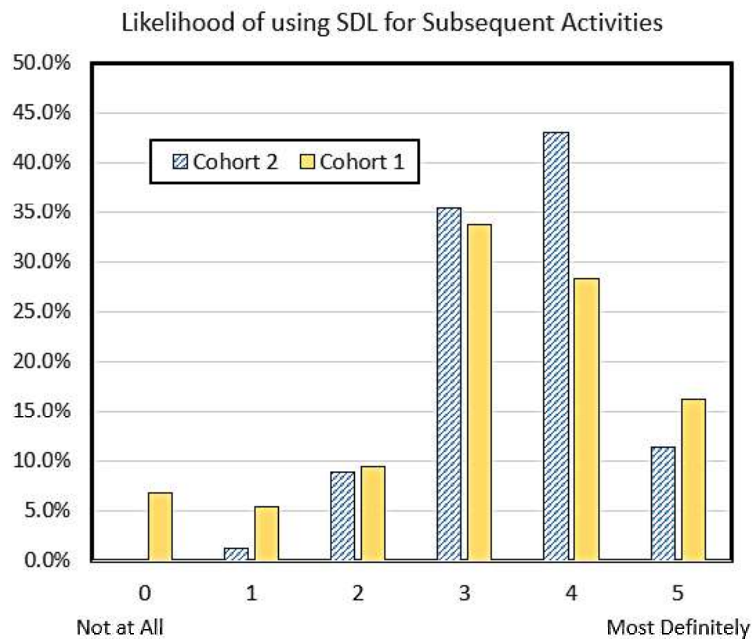


Figure 5. Likelihood of SDL for Subsequent Activities

However, there are also a number of students who disliked the approach taken to bring out their awareness on the importance of SDL, especially in the earlier activities on laboratory skills where they need to suggest their procedures. Some expressed frustration when the team intentionally let them make mistakes in the learning activities. For example, one student commented that it was: "*Unfair to all as everyone wastes time making mistakes. I feel that it would be better to teach students the solution to the problem, then let students have the freedom to expand their knowledge by intentionally making mistakes to learn from that. That way, each person's learning can be quantified by their passion/interest in their course.*" Some of these students felt they are not yet ready for SDL, or simply preferred to be lectured in the traditional way.

On the other hand, there are also students who appeared more positive and did not find the approach frustrating for them, saying: "*I feel that it is quite effective as it allows students to be proactive and learn by themselves before the class starts. It also allows students to be more self-disciplined and not always rely on the lecturers*". One student suggested that the correct procedures be given after they were told of the mistakes, instead of making them rewrite the procedures. Another student was able to see beyond the immediate situation, and commented: "*I understand that it's an important skill that can be useful in the future since there's no one whose going to handhold is and teaching us everything in the future when we go to work.*"

## MOVING FORWARD

Such findings are perhaps not surprising, given that we have a total of 145 students of varying academic abilities and motivations towards study, especially when there is a sizeable number where chemical engineering is not even their top 3 choice of courses.

We had also gained important insight into students' perceptions of SDL. While the majority of respondents agreed that SDL is an important competency to acquire, there remained a handful who felt that they could manage their own learning by using their own approaches. When asked the question, "*How do you see the usefulness of the Self-Directed Learning Model in relation to you in learning new things*? Select one option,"; a significant number of students chose the response: "*No, as I feel my own way of learning is still better*." This finding is consistent from the 2 runs: 7.23% out of 83 valid responses for the second run, compared to 6.25% out of 80 valid responses for the first run. A future survey may need to unearth via open-ended question what are the students' current approaches are. The concern here is that some may still rely on rote learning 'honed' through years of secondary school education, which may still work to a limited extend in year 1 of study.We will also review again the learning tasks for the module, not only for P05 and P06 but, more importantly, for the 3 earlier learning tasks, which focus on laboratory skills. In particular, we will completely redesign the first learning task (P01, in week 2) to demonstrate how the steps in the SDL model can be modeled. In the present approach, we simply assumed that students are already comfortable with laboratory skills, having acquitted them from the previous semester (Stage 1A). Hence, we just "bolted on" the SDL model (as covered in week 1) and expect students to use it for laboratory skills; and focus on further developing SDL skills in process skills.

Lastly, the approach to date in supporting the development of SDL skills is still the typical "one size fits all" design. Given the constraints of available resources (equipment, laboratory space, etc.), we are not able to offer individualized coaching that matches the different levels of SDL abilities. In any case, all the workshops and activities are group-based, and students will invariably "parceled-out" the work to be done among themselves, often with an unequal amount of responsibilities. With the availability of affordable Web 2.0 Tools, we may be able to provide more differentiated support mechanisms for students with different learning challenges. An area of improvement is making the guidance questions (Table 2) available "on-demand" via the school intranet, instead of in table form in the appendix of the manual. More importantly, in line with the spirit of self-directed learning, we need to engage students more in taking responsibility for their learning, in the form of self-assessment (Boud, 1995). We intend to supplement the sample reports with the use of evaluation rubrics so that students can better understand the assessment criteria and be able to monitor and evaluate their work. We will need to review the scheduling of the activities (Figure 3) to provide more opportunities for giving students feedback on their work.

## CONCLUSION

This paper shares the design of learning tasks to integrate SDL into an engineering curriculum using the CDIO Framework. Although the specific example used pertains to chemical engineering, the approach applies to any discipline. Important learning points include the need to better understand the students' readiness for SDL, especially when dealing with a cohort with diverse academic backgrounds. There are still many rooms for improvement, and we are learning as we travel along this journey. Future works will make greater use of technology to provide more customized assistance to students with different learning needs to develop their SDL competency.

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**Appendix 1. Generic Descriptors for TSC Levels in Skills Framework**

| Level | Responsibility (Degree of supervision and accountability) | Autonomy (Degree of decision-making) | Complexity (Degree of difficulty of situations and tasks) | Knowledge and Abilities (Required to support work as described under Responsibility, Autonomy, and Complexity) |
|---|---|---|---|---|
| 6 | Accountable for a significant area of work, strategy or overall direction | Empower to chart direction and practices within and outside of work (including professional field/community), to achieve/ exceed work results | Complex | • Synthesise knowledge issues in a field of work and the interface between different fields, and create new forms of knowledge<br>• Employ advanced skills, to solve critical problems and formulate new structures, and/or to redefine existing knowledge or professional practice<br>• Demonstrate exemplary ability to innovate, and formulate ideas and structures |
| 5 | Accountable for achieving assigned objectives, decisions made by self and others | Provide leadership to achieve desired work results; Manage resources, set milestones and drive work | Complex | • Evaluate factual and advanced conceptual knowledge within a field of work, involving a critical understanding of theories and principles<br>• Select and apply an advanced range of cognitive and technical skills, demonstrating mastery and innovation, to devise solutions to solve complex and unpredictable problems in a specialised field of work<br>• Manage and drive complex work activities |
| 4 | Work under broad direction<br>Hold accountability for the performance of self and others | Exercise judgment; Adapt and influence to achieve work performance | Less routine | • Evaluate and develop factual and conceptual knowledge within a field of work<br>• Select and apply a range of cognitive and technical skills to solve non-routine/abstract problems<br>• Manage work activities which may be unpredictable<br>• Facilitate the implementation of innovation |
| 3 | Work under broad direction<br>May hold some accountability for the performance of others, in addition to self | Use discretion in identifying and responding to issues, work with others and contribute to work performance | Less routine | • Apply relevant procedural and conceptual knowledge, and skills to perform differentiated work activities and manage changes<br>• Able to collaborate with others to identify value-adding opportunities |
| 2 | Work with some supervision<br>Accountable for a broader set of tasks assigned | Use limited discretion in resolving issues or inquiries. Work without frequently looking to others for guidance | Routine | • Understand and apply factual and procedural knowledge in a field of work<br>• Apply basic cognitive and technical skills to carry out defined tasks and to solve routine problems using simple procedures and tools<br>• Present ideas and improve work |
| 1 | Work under the direct supervision<br>Accountable for tasks assigned | Minimal discretion required. Expected to seek guidance | Routine | • Recall factual and procedural knowledge<br>• Apply basic skills to carry out defined tasks<br>• Identify opportunities for minor adjustments to work tasks |