DESIGNING ACTIVE LEARNING EXPERIENCES FOR A FIRST-YEAR INTRODUCTION TO CHEMICAL ENGINEERING MODULE: LESSONS LEARNT

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ABSTRACT

This paper summarizes the experience of implementing CDIO framework into a 3-year Diploma in Chemical Engineering curriculum at Singapore Polytechnic, focusing on the Year-1 module, *Introduction to Chemical Engineering*. This introductory module was initially introduced in April 2008 to all first year Chemical Engineering students at Singapore Polytechnic.

The paper firstly compares the more active and experiential learning approach advocated by CDIO with more traditional approaches to teaching, which continue to be the main stay of teaching in the Polytechnic. Secondly, it goes on to describe the approach taken by the module team when developing the Introduction to Engineering module, which aim to expose students to the real world of chemical engineering, showing the diversity of practical applications and familiarizing them with key developments and challenges in the field. Emphasis is placed on designing out-of-classroom activities to provide meaningful active learning experiences that build around a brief but integrated curriculum, including a simple design-built experience.

Finally, from initial evaluation, based on staff observations and reflection, as well as student feedback via questionnaires and blogs, the paper shares the learning experiences of the team and present framing for future CDIO curriculum development.

KEYWORDS

Chemical engineering, CDIO, active learning, experiential learning, design-build experience

INTRODUCTION

The Diploma in Chemical Engineering course adopted the CDIO framework as the basis to revamp its curriculum, and as part of the revamp effort, a new module entitled *Introduction to Chemical Engineering* is introduced. Details of the curriculum revamp have been covered in detail elsewhere (Cheah, 2009)[1]. This paper focused on the work done on the module, documenting the development aspects of course design that deviates from traditional practice as well as the key lessons learnt.

The module *Introduction to Chemical Engineering* is designed for target Year 1 students, to expose the discipline to the newly enrolled students fresh from their O-Levels. The introduction of this module into the chemical engineering curriculum is a direct response to the requirement of CDIO Standard 4 which specifies that an introductory course should be included in an engineering curriculum to provide the framework for that engineering practice in product and system building, as well as to introduce to students the essential personal and interpersonal skills.

The importance of this apparently simple requirement cannot be understated. Many of the students selected the course via online application without making the trip down to the institution for course counselling during the Joint Admission Exercise. Instead, they merely relied on general information provided by course speakers during one of the school promotion talks prior to the O-Level Examinations. The module introduces students to the chemical engineering profession, the chemical industry, roles and responsibilities of a chemical engineer; and supplemented with activities designed to offer some appreciation of the kind of job that a typical chemical engineer does. The aim is to give the students a greater appreciation at an early stage, of their course of study, and hopefully will kindle their spirit for learning chemical engineering. The best approach to achieve this aim is to design the curriculum using active learning.

INSTRUCTIONAL STRATEGIES IN SINGAPORE POLYTECHNIC

Singapore Polytechnic follows a 2-semester Academic Calendar system. All full-time diploma programs in the polytechnic are 3 years in duration, and are completed over 6 semesters. Most diploma programs follow the modular system in the so-called flip-flop model. This means that any intake of students is typically divided into 2 cohorts, one in each stage, namely Stage A and Stage B respectively. Students in Stage A will complete a set of modules in one semester, while that in Stage B will study a different set of modules in the semester. The following semester, students from these two stages will swap the modules that are being studied.

Broadly speaking, the main instructional strategies used in the Polytechnic consist of a combination of 3 components, namely Lecture, Tutorial and Practical, in the so-called LTP model. Practical refers to the hands-on component of learning, which typically consists of experiments in laboratory or workshops. The curriculum are all designed around the LTP models, with the curriculum hours distributed between these 3 components, or between L and T for modules without the practical component. The advantage of this approach is that it facilitates the timetabling for each course.

As a general practice, the First Year lectures and tutorials are usually conducted in small class sizes of 20-24 students in media classrooms rather than in lecture theatres. This is to ensure adequate attention can be given to all students so as to ease the transition from secondary school to polytechnic education.

THE TRADITIONAL TEACHING APPROACH VS ACTIVE LEARNING

Until recently, the most common instructional strategy used in this polytechnic, much like other institutions of higher learning (IHLs), is the traditional lecture. A traditional lecture is a highly efficient means of presenting a large amount of information to a large number of students. However, simple presentation of information does not constitute transfer of information from the lecturer to the student. During a traditional lecture, the only one who is really active is the lecturer – talking, writing on the board, showing transparencies, asking questions and often supplying the answers when there is no response from the class. The students are passive – watching, listening and maybe taking notes, but seldom actively thinking about the material being presented. Typically, students sitting passively in a lecture will tend to drift away and, the longer they sit, the more this is likely to occur. After a while, the lecture can become no more than “background noise”.

Thorndike[2] (1910) had long ago recognized the limitations of the lecture model. It is now well established that information that is transferred will be of no use to a student if it is not retained. Lastly, information also needs to be integrated and transformed into knowledge if that information is to be generalized to solve new problems.

A number of alternative instructional strategies are currently being practiced and promoted in IHLs as a means of overcoming this limitation. These include (but are not limited to) cooperative learning (Johnson, Johnson, & Smith[3] 1991a, 1991b; Millis & Cottell[4], 1998), case teaching (Christensen & Hansen[5], 1987), classroom assessment (Angelo & Cross[6], 1993), writing across the curriculum (Young & Fulwiler[7], 1986), and writing to learn (Young[8] 1997). These strategies fall under the general rubric of active learning. Bonwell and Eison[9] (1991) note that while definitions of the term "active learning" vary, most agree that, when actively engaged, students are involved in more than just listening to the lecturer talking.

Active learning is anything that happens in a class that engages students with the learning material being presented. Students might be called on to work individually or in small groups for brief periods of time to answer questions, brainstorm ideas, conduct some research, or to think of questions about the material just lectured on. At the end of the allotted period, the lecturer calls on several individuals or teams for their responses, then collects more responses from volunteers, and moves on when the correct answer has been obtained and it seems clear that the students understand it.

COURSE DESIGN

The course development team set out to design this course with active learning in mind. The team wanted to expose students to the world of chemical engineering using a combination of lectures, tutorial and laboratory activities. Also from the onset, it is clear that this module cannot follow the flip-flop model. It is of utmost importance that all students fresh from their O-level be exposed to the module in Semester 1, so that we can stimulate their interest in, and strengthen their motivation for, the field of chemical engineering by focusing on the application of relevant core chemical engineering disciplines.

Another benefit of requiring all students to take this module in Semester 1 is that all students will be equipped with the necessary knowledge in two of the most important topics in any engineering studies, which are units and dimensions, and basic engineering measurements. In the flip-flop model, half the students will not have learnt these topics until they reach Semester 2. This posed great difficulties for these students in Semester 1, having to struggle with these concepts while at the same time learning other topics such as energy balance and thermodynamics.

In terms of technical content, the material covered in this module is very elementary. The module introduces students to the chemical industry in general, with special emphasis on Singapore.

To supplement the practicals, the module also includes an industrial plant visit to expose students to a real-world manufacturing plant where they can see first-hand the scope and size of operation of a typical chemical engineering company. Students get to see how the raw materials are transformed into useful products through various unit operations such as fermentation, distillation, filtration, etc. It also serves to provide students with the right perspective on the nature and type of working environment, as well as the importance of various plant utilities such as cooling water, steam and compressed air.

Lastly, to provide an integrated learning experience incorporating various soft skills, a mini Design-Build Experience (DBE) was introduced at the end of the module study. The inclusion of the DBE is consistent with CDIO Standard 5 which stipulates that a curriculum should includes two or more design-build experiences, including one at a basic level and one at an advanced level. For this module, the DBE comes in the form of a Do-It-Yourself (DIY) project whereby students are required to work in a team of 3 to 4 members to fabricate a water filtration kit. This project has injected some elements of uncertainty into the students' work where the filter can be constructed in various ways and there is no right or wrong answer. This module therefore serves to provide them with a more authentic view on technology and engineering in the real world context.

PRELIMINARY FEEDBACK

As this module was conducted for the first time, student feedback has been obtained for evaluation to identify the impact of the curriculum changes and possible improve aspects of the module. A small group of students have volunteered in providing this feedback on a blog using a questionnaire. The questions used are:

1. In this week's *Introduction to Chemical Engineering* lessons, what task / activity / experience improved your understanding or ability in any of the following skill areas such as "Thinking", "Managing your learning", "Communication" or "Teamwork "?

2. Briefly describe the task / activity / experience.

3. What was good about the task / activity / experience that helped you to understand and / or learn the skill?

4. Other comments, e.g. How can you learn these skills better?

From the initial data, based on staff observations and reflection, as well as student feedback via blogs with questionnaires, the following section of the paper shares the key learning experiences so far, and our present framing for future CDIO curriculum development.

INFUSION OF CDIO SKILLS

At the polytechnic level, it was decided that we started with introduction of 3 CDIO skills – namely (2.4) Personal Skills and Attitudes, (3.1) Teamwork, (3.2) Communication and (4) Introduction to Engineering; every diploma is at its liberty to try out integration of other skills as well. By starting small, the team gained valuable experience on how to integrate the basic CDIO skills into a technical curriculum. This provided the team members with the necessary confidence to explore integration of other skills on their own. The lesson learnt here is that to be familiar with the ways to integrate a particular CDIO skill so that other skills can be incorporated similarly without too much difficulty. The challenge has shifted to the ability to peg the content at the level comfortable to Year 1 students, and to do so without being carried away and incurring too much additional curriculum hours. A brief introduction on CDIO is also covered in this module.

Another important intention is to get students to get accustomed to occasions whereby the lecturer will not necessarily cover all tutorial questions in class. Students typically expect to obtain all the "right" answers from the lecturer. Edstrom et al (2003) noted that students often have a "right-or-wrong" view on technical knowledge. This is similar to the Year 1 students who went through the O-Level examinations prior to joining the polytechnic education. In preparation to the O-Level examinations, 10-year series book is available for students to practice similar examination questions. This book contains the past 10 years O-Level examination questions with model answers attached at the back of the book. By continuously practicing these exercises, the students are accustomed to getting the "right" answer and not able to think outside the box. The most frustrating part is that students tend to be satisfied when they have arrived at the correct answer, regardless of the process in which the answers were reached. The application of knowledge is limited.

In the engineering curriculum, often the fundamental concepts and principles are interlinked in one way or another and applied in various contexts. Thus, the team has designed tutorial questions and activities which require the application of fundamental knowledge and some forms of system thinking before the final answer can be reached.

Furthermore, students also feel uneasy with vague questions or questions with multiple possible answers as their prior education experiences do not contain these exposures. Thus, when they enter the polytechnic education system, many of them have difficulties in coping with the curriculum that emphasizes more on the application of concepts, as opposed to regurgitating facts and number crunching.

Students who have undertaken this module during their first semester studies acknowledged that the CDIO skills have benefited them, as supported by the student feedback as follows:

> "The activity allows me to experience what is it like where a group of engineers sit down together to discuss on the addition of a new equipment to the plant, thus improving my communication skills with my peers."

> "While doing the experiment, I find that I could better communicate with my group members. This helps me to understand my group members better thus allowing the experiment to be carried out without much problems occurring."

The student feedback served as indications that the module design approach was carried out appropriately. As a result of adopting CDIO Standard 4, this introductory module has provided the framework for engineering practice in product and system building. The students felt that this module stimulated their interest in chemical engineering, as illustrated through the student feedback as follows:

> "The good thing is that the experiment gave us a small hole to peek into the real job on how even a small pump requires lots of information and also the people needed to contact about the new pump. The bad thing is that it doesn't feel like doing an experiment."

BETTER ORGANISATION AND ADMINISTRATION OF THE CURRICULUM

The module is designed as a 45-hour module. The 45-hour coverage is divided, for convenience of the Lecture, Tutorial, Practical (L:T:P) classification, as 1:1:1, which means that each week, there is one hour of Lecture, one hour of Tutorial and one hour of Practical. The actual conduct of the lesson, however, deviates from this.

The concept of units and dimensions and basic engineering measurements are taught in the Lecture hour. The Tutorial and Practical hours are used to reinforce the concepts taught in Lecture. Practical lessons are only conducted after 7 weeks. This is to ensure students to gain a good grasp of the fundamental knowledge first because these knowledge are requisites in other engineering modules.

As the one-hour Practical has been timetabled after the one-hour Tutorial, this creates a 2-hour time slot which could be use for conducting tutorial lessons or laboratory activities. With this flexibility, laboratory activities were designed to enable students to understand the roles and responsibilities of a chemical engineer, expose themselves to the real world of chemical engineering, practice the application of theoretical knowledge and familiarise with developments and challenges in the field. From the eighth week onwards, students carry out their laboratory activities during this 2-hours time slot while the Lecture continues as per normal.

In addition, the team realized the usefulness of lesson plans. In the past, lecturers tend to resist the use of lesson plans as their preparation is viewed as too time consuming, plus the attitude that “of course I know what I am teaching, why should I need one?”. When the module was first rolled out, it was taught by the team of two lecturers, i.e. the paper’s authors. In the future, it is hoped that other lecturers will undertake the teaching of this module as well, so that everyone is familiar with the intended learning outcomes and subsequently better reinforce them in their own respective modules. It is also a common phenomenon that different lectures can approach the same topic in different manners.

In our situation, the main objective is to ensure that all six classes of students will receive the same knowledge about CDIO skills that is intended to impart on them. The module was primarily designed to acquaint new students with the discipline and learn soft skills in a technical context, and not so much on testing technical knowledge. Therefore, there is a strong need to “standardize” the course materials in terms of intended learning outcomes, especially in the laboratory activities. To this end, the team is convinced that a lesson plan is crucial to ensure that every lecturer can impart the intended teaching points to all students. The lesson plan also serves to alert the lecturers to the correct demonstration of the desired learning behaviour by students.

USE OF A RANGE OF ACTIVE LEARNING METHODS (INCLUDING E-LEARNING)

The module team made use of readily available information in the World Wide Web (WWW). For example, information on what chemical engineering is all about or what a chemical engineer does, where a chemical engineer works, etc can easily be obtained from university websites. Information of unit operations and plant utilities are readily available from vendor companies and chemical engineering companies. Ethics and code of practice can be obtained from websites of Institution of Chemical Engineers or National Society of Professional Engineers.

This generation of students are IT savvy. They also possess their own laptop in line with the Singapore Polytechnic’s initiative to adopt the utilisation of notebooks in the curriculum. Tutorials exercises have been designed to appeal to the Internet-savvy students. The exercises require students to make extensive use of the WWW to search for relevant information and write their answers using their own words. Through the student feedback, the students have found that these exercises were enriching as illustrated as follows:

> “Those questions are relevant to our future study or career. Besides that, those practical questions are research based – allow us to experience research especially via internet.”

From the past, students have demonstrated that they could not differentiate factual from fictional information searched from the WWW, especially technical information. Thus, it was necessary educate the students the right approach starting from the beginning of their polytechnic education.

Besides, opportunities were also created to allow them to share knowledge through discussion threads made available in Blackboard Academic Suite, an e-learning platform in the WWW.

For example, using the Bhopal Disaster, the team posed some basic information on the Blackboard site, and students are required to read them and then carry out further search using the WWW. A classroom discussion was then held and students were asked to express their views. Students are also asked to challenge their classmates' viewpoints as well as defending their own. However, most students probably do not remember much about the discussion after the discussion has ended, except the studious ones who have taken some notes. Thus, a discussion forum was created for students to carry on the debate beyond the stipulated lesson time. With the availability of discussion threads in the WWW, students post their viewpoints and arguments at the website. Other students from other classes who have been given the access will be able to read these threads and learn from one another. As long as the threads are maintained in the website, students can always refer to it as and when it is needed at their own time.

It was also observed that there were some students who rarely contribute to discussions in class. They are normally shy or lack of confidence to speak out in front of an audience or they are just plain quiet students. Lecturers are usually concerned with these students as it is difficult to ascertain whether these students are following the discussion in class or their minds have drifted away. However, when the students are required to pen their thoughts in the discussion thread, these quiet students were more motivated to contribute one on their own, although the exercise can be done in group of 3 to 4 students. This could be one of the many ways for lecturers to reach out to students who seldom express themselves in class and indirectly check for their grasp of concepts.

Students generally prefer activity based or case study type of exercises as it helped them to learn better and apply some form of system thinking. Hands-on learning with the pilot plant allows them to practice what they have learnt in theory. The way the activities are facilitated also plays an important role to ensure that students are given the opportunities to think first before concluding the final answer or making a firm decision. Here is what the students have to say:

> "We faced a few questions when drawing the flow diagram. We penned our questions, and our lecturer gave us cue instead of direct answer – this allows us to think."

> "One thing good about this experiment is that is allows me to do critical thinking, thus it allow me to think more in an assistant engineer point of view rather than in a SP student point of view."

However, there are always room for improvements as there were also comments from students that some of the activities were too easy and boring. More interesting tasks should be incorporated, such as:

> "I would like to have more problem base activities, some relevant or common problem that will occur in our real working area."

> "I think these skills could be better learnt if we were given a chance to run the plant that has a situation in it and the group has to solve the situation. I think through this type of activities the group can then fully exhibit the following skills: Thinking, Managing your Learning, Communication or Teamwork."

When the activities were designed, it is not the team's intention to create experiments as per se. The laboratory activities were crafted to allow the students to experience the engineering practice in smaller scales. However, some students still could not recognise the fact that the activities in this module are not experiments. This is mainly because experiments are still being carried out in other modules.

INTERGRATION OF CDIO SKILLS IN OTHER MODULES

Using an outcome-based approach in assessment of learning outcome, it helped to promote clearer and creative thinking in curriculum development. It is again the experience of the authors that, on more than one occasion, a new idea emerged during brainstorming sessions to overcome a particular problem with the implementation plan. In one instance, the team faced with the possible clash of usage of equipment with another diploma for one of the practicals. The practical of concern involved that of measurement of hydrostatic pressure. After some deliberations, it struck the team that the desired learning outcome can be achieved by using another mothballed pilot plant that was not in use and waiting to be written-off. And once the new idea takes root, the team proceeded to come up with more new ideas to use the pilot plant for the practical of other modules in subsequent years, specifically for level measurement in the Year-2 module *Process Instrumentation*, and level control in the Year-3 module *Process Control*. Similarly, the practical on rotameter calibration makes use of the same pilot plants as another Year-2 module *Chemical Reaction Engineering*.

Motivated by these achievements, the team subsequently made use of other pilot plants with low-utilization rates, for example the Active Pharmaceutical Ingredient (API) pilot plant and reverse osmosis pilot plant. This not only boost the usage of these expensive pilot plants, but also exposes students early to different types of unit operations in chemical engineering. Having some familiarity with these plants early in their course of study, it is hoped that students can recall the concepts that they learnt in Year 1 when they perform some experiments on the same pilot plants in Year 2. Hopefully this will address some of the common problems of students not remembering what they learnt or failing to see the relevance or connection between different modules.

FUTURE WORK

The team, having familiarized with the work done with the integration of the first 3 skills, saw opportunities to incorporate aspects of (2.5) “Professional Skills and Attitudes” and (4.1) “External and Societal Context” into the module as required by CDIO Standard 4. In this regards, coverage of (4.1.2) “Impact of Engineering on Society” and (4.1.4) “Develop a Global Perspective” can be achieved through assignment and classroom discussion of the Bhopal Disaster.

In a similar manner, the team also exposed students to ethics – specifically the coverage of (2.5.1) “Evaluate the Impact of Values and Ethics” and (2.5.2) “Demonstrate Professional Behaviour at Work and in Society” – via a case study on a Singaporean chemical engineer on attachment in a foreign country where drinking is permitted in the workplace. Likewise, (2.5.3) “Staying Current on Emerging Research and Practices in Your Field” focuses on the discussion of impact of biofuels on the environment especially food production, and reinforce the roles and responsibilities of chemical engineer to solve the problem via innovative means, e.g. using algae.

CONCLUSION

The CDIO framework has indeed benefited our students and made engineering education more interesting. The significant factor when developing this introductory module is proper design of laboratory activities and questions. The types of question include case studies, questions that require some information searching from the WWW, concept questions that involve system thinking and managing their own learning. By having a variety of learning activities, students are given the exposure to be versatile.

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