INTEGRATING CDIO SKILLS IN A CORE CHEMICAL ENGINEERING MODULE: A CASE STUDY

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ABSTRACT

The Diploma in Chemical Engineering is one of the engineering programs in Singapore Polytechnic adopting the CDIO Framework as the basis of its curriculum revamp. This paper describes the work done on *Chemical Reaction Engineering*, one of the core modules in chemical engineering disciplines. Specifically, it detailed the work done on revamping of the laboratory experiments for the module, with the aim on integrating the topic with other chemical engineering disciplines as well as infusing three CDIO skills viz Teamwork, Communication, and Personal Skills and Attitudes, focusing on critical thinking skills, and ability to hold multiple perspectives. It described the rationale behind the redesign of laboratory experiments to contextualize the various soft skills so as to provide a learning environment that bear relevance to real-world work environment that students can appreciate. The design of assessment schemes to encourage both individual mastery and team collaboration was illustrated. This is followed by a discussion of student experience through blogs and survey questionnaire. Some points of reflections based on the lesson learnt were then presented, followed by an outline of follow-up actions and the challenges of implementing them.

KEYWORDS

CDIO, chemical engineering, chemical reaction engineering, assessment, evaluation

CDIO AND THE REVAMP OF THE DIPLOMA IN CHEMICAL ENGINEERING

Singapore Polytechnic had adopted the CDIO Framework as the basis for the design of all its engineering diplomas. All new engineering diplomas will need to be designed around the framework, and all existing diplomas will need to be revamped to integrate the various CDIO skills, guided by the 12 CDIO Standards and CDIO Syllabus. The revamp exercise for the Diploma in Chemical Engineering had been covered elsewhere by the author [1]. This paper focuses on the work done for a specific module, namely *Chemical Reaction Engineering*.

Chemical Reaction Engineering

The module is taught to Year 2 students from the Diploma in Chemical Engineering. Broadly speaking, the module aims to provide students with fundamentals of chemical kinetics and reactor design. In chemical kinetics, factors affecting the rate of reaction and the determination of rate equation are discussed. In reactor design, various types of industrial reactors are introduced and the development of design equations and sizing of reactors are covered. This is complemented by extensive practical work.

USING CDIO FOR MODULE REDESIGN

The revamp of the module focuses on the redesign of laboratory experiments for the module. From the onset, it is clear that our laboratory experiments, which are rich in hands-on experience, are the most conducive place to introduce various CDIO skills. This is because unlike lectures and tutorials, laboratory sessions deal with a much smaller number of students each time, roughly between 18-24 students, as opposed to lectures (60 or more students) or tutorials (around 40 students). By redesigning our laboratory activities in an innovative manner, they can be leveraged to provide the largest context on which infusion of CDIO skills can be initiated. Revamp of the laboratory activities follows the student-centred Triangle of Course Design [2] shown in Figure 1. The module coordinator together with a senior education advisor reviewed all the module learning objectives and recast them in terms of the intended learning outcomes.

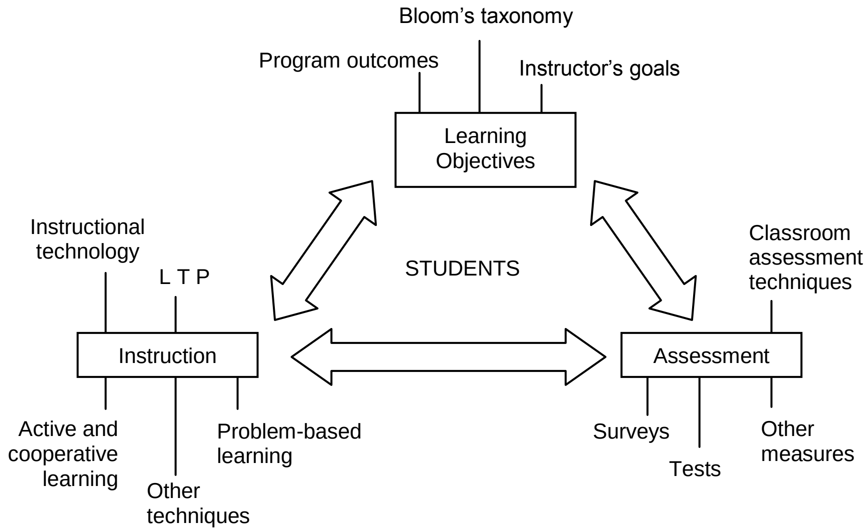

Figure 1. Student-centred approach to curriculum design

A sample of the learning objectives is provided in Figure 2. The details of this work had been covered in a separate paper by the team [3]. Suffice to say the various learning tasks in this module, be it communication skills, teamwork, etc were all contextualized to provide an active, experiential learning experience for the students. The module also included a mini design-build experience (DBE) where students are required to first determine the size of a reactor required for a given product conversion, and then proceed to fabricate one out of plastic tubing, and lastly evaluate its performance by carrying out a laboratory experiment. A comprehensive student guide was also developed to accompany the module, complete with explanation of the desired learning attitudes, underpinning knowledge of the selected CDIO skills, along with a complete set of rubrics for used in the assessment of the required demonstration of the CDIO skills.

The followings serve as the basis for the redesign of laboratory activities:

(a) Moved away from merely "laboratory" environment, but instead to towards a contextualized to reflect working environment in the chemical industry or chemical research institutes where our graduates eventually find employment.

(b) Moved away from merely proving theories, and towards integration of other related technical content, along with the desired CDIO skills.

For (a), all lab experiments were replaced by scenario-based activities, whereby for each activity, students were placed under simulated working environment that a chemical engineering graduate typically finds himself/herself in. This is achieved by re-writing the entire laboratory manual, with a new section on “Task Scenario” placed at the beginning of each activity (See Figure 3), while the usual “Experimental Procedures” were “relegated” to the Appendix, where it is referenced from the Scenario. A special section on underpinning technical knowledge required was also added and was placed in the Appendix as well. This is to address one of the challenges inherently faced in the teaching of any chemical engineering module that contains a laboratory component: that of mismatch between learning underpinning knowledge in lecture and practice sessions in the laboratory.

<u>AFTER</u>

2	**Obtain the Rate Law for specific chemical reactions**
2.1	Describe the steps involved for determining the rate law parameters.
2.2	Use Arrhenius Law to determine the effect of temperature on the rate of chemical reactions.
2.3	Infer and interpret experimental data on the effect of temperature on the rate of chemical reactions.
2.4	Compare and contrast the integral and differential methods of analysis in rate law determination.
2.5	Use integral and differentiated methods of analysis to determine the rate law for a liquid reaction.
2.6	Calculate and interpret the results for the integral and differential methods of analysis using graphical solution and linear regression.
2.7	Identify the components of an effective team
2.8	Identify team roles and their impact on team performance
2.9	Apply team ground-rules and display teamwork (including leadership) in a range of team role situations when conducting experiments
2.10	Identify contradictory perspectives relating to modifications of a chemical reactor.
2.11	Design appropriate communication strategies and deliver effective oral communication to a given audience.

<u>BEFORE</u>

2	**Understand the fundamentals of chemical kinetics**
2.1	Distinguish between elementary and non-elementary reactions.
2.2	Explain the rate law and rate constant for elementary reactions.
2.3	Describe the temperature dependence of the rate constant using Arrhenius Equation.
2.4	Explain the molecularity and order of reaction.
2.5	Discuss the factors affecting the rate of reaction.
2.6	Determine the frequency factor and activation energy of a reaction.
3	**Understand the methods for determining the rate law for liquid reactions**
3.1	Describe the steps involved for determining the rate law parameters.
3.2	Compare and contrast the integral and differential methods of analysis in rate law determination.

Figure 2. Comparison between Learning Objectives before and after revamp

For (b), again a complete review of all the laboratory experiments was carried out. It was clearly evident that one of the five experiments do not serves much purpose other than confirming what were already taught in class. In the original design of the particular experiment, students carry out measurements of conversion of a chemical reaction at various points along the length of a chemical reactor, and hence verify that the concentration of feed materials decreases as it progressed down the reactor. This is rightly so, as the feed materials got consumed and formed products in the reactor. This experiment was therefore replaced with one that incorporates a mini design-built experience (DBE), as well as exposing students to some degree of design ambiguity that requires them to make sound engineering decision by making reasoned choices. This is a deliberate move to create the awareness that at times more than one acceptable design are possible and that trade-offs between different designs must be considered.

Integration of desired CDIO skills is based on the rationale soft skills and disciplinary knowledge are largely interdependent, and they should therefore be learnt and assessed together. To this end, all the activities in the laboratory require students to practice various soft skills in the technical context, based on the situation described in the task scenario. The underpinning knowledge for these CDIO skills were briefed to students and also made available in the student guide. Figure 4 provides the underpinning knowledge on Managing Learning.

> You are the Engineering Assistant in Tokkong Engineering Pte Ltd, a local chemical engineering company specializing in engineering design and integration of chemical pilot plants. The company's major clients include the universities and polytechnics, research institutions and laboratories. You report to Mr. Pow Kah Leow, the Project Engineer who designed pilot plants according to client requirements. You are in charge of performing test run on the pilot plants. The purpose of performing the test run is to ensure that the pilot plant is capable of performing according to its design specifications. You have a team of 3 – 4 technicians under your supervision.
>
> A major customer, the Singapore Institute of Technical Studies (SITS), had ordered a chemical reactor test rig consisting of 2 types of reactor, namely the continuous stirred tank reactor (CSTR) and the plug flow tubular reactor (PFTR). A brief description of the system is shown in Appendix 1, and Appendix 2 is a set of experimental procedure developed by the Project Engineer for achieving the following stated objective:
>
> "*To compare the performance of a CSTR and a PFTR*"
>
> The Project Engineer informed you that the reactor test rig has been delivered to Institute of Technical Studies, and your team will be required to perform a test run in presence of a group of lecturers led by the Lecturer-in-Charge, Dr. Chin Khan Khor, for the site acceptance test. At the completion of the test run, you will be required to draft a written memo on behalf of the Project Engineer, to the lecturer-in-charge, detailing preliminary findings from the test run, concluding if the reactor test rig is functioning as expected.

Figure 3. Sample Task Scenario

- What is a learning approach and how does it impact on personal learning. Typical differences in the way people approach their learning (e.g., visual, auditory, kinaesthetic; holistic, serialist, etc)
- Different ways in which self improvement can be achieved (e.g., lifelong learning, creating positive beliefs and psychological states, etc).
- The challenges that lifelong learning entails and its implications (continual re-skilling, job changes, professional and personal flexibility, etc)
- What are positive beliefs and psychological states. How these can be developed and maintained (e.g., reframing, visualizing, self-motivation, etc)
- What is meant by dispositions and how they impact on human behaviour. How certain dispositions (e.g., initiative, perseverance, flexibility, etc) contribute to high performance and success in work projects and in life goals.
- What is meant by 'learning strategies and skills' and how they can help to make learning more effective and efficient. Different types of learning strategies and skills and how they contribute to improved learning (e.g., goal setting, learning plans, monitoring learning, organizing/summarizing information, receiving feedback, etc)
- Ways to manage time and resources (e.g., schedules, monitoring and review, etc)

Figure 4. Underpinning Knowledge for "Managing Learning"

ASSESSMENT DESIGN

Assessment is the most powerful tool to guide and support student learning (Edstrom et al, 2005). Detailed planning went into the design of assessment questions. Coverage of assessment is comprehensive, ranging from the underpinning technical knowledge to various CDIO skills. A complete breakdown of the assessment scheme for each activity was provided in the student guide. A sample of this is shown in Figure 5.

This Activity will be assessed based on the following components:

S/N	Components	Weightage	Individual	Group
1	Punctuality and Attire	4%	✓	
2	Laboratory Safety: (a). Safety Practice (b). Explaining safety precautions	 4% 4%	 ✓ ✓	
3	Attitude, Responsibility and Diligence in Conducting Experiments	8%	✓	
4	Pre-Experiment Assessment of Underpinning Knowledge: (a). Key Concepts, Principles, Procedures (b). Oral Presentation	 4% 6%	 ✓ 	 ✓ ✓
5	Teamwork	10%		✓
6	Post-Experiment Assessment: Questions for the Practical	10%	✓	✓
7	Report Assessment	50%		✓

Figure 5. Sample Assessment Scheme for an Activity

To balance between fostering teamwork and collaboration among students on one hand, and encouraging personal skills and attitudes of each individual student on the other, a mixed approach in assessment to reward both efforts were designed. Broadly speaking, the assessment questions can fall into one of three categories:

(a) Single questions for which each student has to answer – students typically choose from a pool of questions
(b) Group questions requiring everyone to answer – the same question requiring different answers from everyone in the group
(c) Group questions requiring a joint answer – questions requiring group discussion and a member of the group to provide the answer

Assessments can be broadly classified as In-Class Assessment and Report Assessment. The In-Class Assessments were carried out at two points in time: first at the beginning of class (the so-called “Pre-Experiment Assessments”; and later during debrief at the end of class – “Post-Experiment Assessments”. As what gets assessed gets learnt, pre-experiment assessments are introduced based on the information made available in the namely the underpinning knowledge and experimental procedures. A set of questions were carefully designed and used to test students understanding prior to allowing them to start the experiment.

Post-assessment questions do not just centre around the work being done in the lab, but serve to stretch student understanding beyond what they learnt in the lab. For the work done in the lab, questions are designed to test their observations of the way the steps are sequenced, test assumptions made in performing the subsequent calculations, and ways to improve the experiment. Questions were also designed for students to integrate what they learnt in other modules into what they learnt in chemical reaction engineering, for example to suggest ways to overcome the hazards posed by a very exothermic chemical reactions, i.e. reactions releasing a large amount of heat, or the impact of their design on pumping requirement if a long reactor with small tube diameter is used versus a shorter one with a larger tube diameter. See Figure 6 which showed samples of the three types of questions that form part of the Pre-Experiment Assessment.

Common questions for the group:

1. Explain your choice of the tube ID selected for your design.
   (Choose 1 member to answer. Common score for the group: 3 marks)
2. Briefly explain what other factors that you would take into consideration in the design of a chemical reactor.
   (1 from each member, 2 marks each)

Each member to choose one of the questions to answer: (3 marks each)

1. Explain what is meant by “plug flow”.
2. Briefly explain, how, in a practical application, a deviation from “plug flow” may occur.
3. Name three assumptions that you made in carrying out the reactor design.
4. Should the analysis of possible sources of error be carried out before or after the experiment? Explain.
5. Explain how the conversion of NaOH will vary along the length of the PFTR.

Figure 6. Sample Pre-Experiment Assessment Questions: Key Concepts

Other than assessing the underpinning knowledge and integration with other technical knowledge, to complement the pre-experiment effort in inculcating greater appreciation of various CDIO skills, assessments were carried out in these areas, such as, (i) team roles; (ii) holding multiple perspectives; (iii) communication – oral presentation and memo; (iv) managing learning. Figure 7 provided some examples on the questions asked for items (i) and (ii) respectively.

<u>Pre-Experiment Preparation</u>: Forming a Team and Allocation of Roles

Divide the workload among your team members to take on the following roles:

1. Supervisor – overall coordination to ensure that procedures are being followed, proper safety precautions are taken
2. Panelman (or Boardman) – monitor the progress of the experiment via PC
3. Senior Technician – monitor proper functioning of conductivity meter and level control system
4. Technician Grade I – perform plant line-up, waste disposal (as and when needed), washing.

<u>Post-Experiment Assessment</u>: Teamwork

Discuss among your team members and answer the following questions:
(All members receive the team mark)

1. Explain the importance of the role of the Supervisor. (3 marks)
2. How do you decide on the allocation of roles? (3 marks)
3. Explain how a failure in the role of (a) Boardman, (b) Senior Technician, would impact the team performance. (4 marks)

<u>Post-Experiment Assessment</u>: Identifying different perspectives

1. Assume you come from one of the following departments, explain your view if the Plant Engineer proposes that an additional high temperature alarm be added to the CSTR pilot plant: (a) Finance (b) Operation (c) Safety
   (d) Maintenance (e) Senior Management
   (1 from each member, 2 marks each)

Figure 7. Sample Activity Design and Assessment

Assessment on critical thinking is achieved via hazard identification and prescription of preventive/control measures, especially in the context of working in the chemical processing industry. In this regards, students are stretched in their thinking process by requiring them to first look for hazard(s) associated with materials and equipment used as well as the process itself under normal and emergency situation. With these, students are required to then explain the necessary safety precautions to be taken to protect themselves, their co-workers and the plant and equipment.

The intended outcome is for students to develop a generic skill on how to properly take a precautionary action against a hazard identified, regardless of what type of chemical plant or work situation they are in. For example, a chemical can pose multiple hazards, e.g. fire/explosion hazard as well as various health hazards. A grinding process poses a different hazard compared to a drying process. Likewise, operating a compressor is different from operating a boiler. By going through the critical thinking process linking causes and effects of a potential hazardous situation, students come to understand the importance that any safety precautionary measure to be taken must match the hazard that is present, as the incorrect measure(s) adopted may convey a false sense of security.

Rubrics were extensively used to aid the assessment of CDIO skills. Figure 8 showed a sample rubric for the assessment on Explaining Safety Precautions.

CATEGORY	LEVEL OF OUTCOME			
	4	**3**	**2**	**1**
Laboratory Safety: **Explaining Safety Precautions**	Clearly identified a hazard, satisfactorily explained how it may arise, and able to link it to the proper safety precaution to take.	Identified a hazard, attempted to explain how it may arise, some attempt to come up with proper safety precaution.	Identified a hazard but unable explain how it may arise, or to link it to a proper safety precaution. Sign of guessing the answers.	Inability to identify a hazard, or attempt to go straight into safety precaution without associating it with a hazard.

Figure 8. Sample Scoring Rubric for Explaining Safety Precautions

All expectations and assessment requirements were communicated to students on the first week at the beginning of the semester. All the materials were also made available electronically in the school's e-Learning platform. Another important feature of the assessment system is that of feedback. Instant feedback was given to students on their performance in the laboratory. Both positive and 'negative' (areas for improvement) ones were conveyed to students during the post-experiment assessment. Feedback on report submission was given 2 week later, after the report was marked.

EVALUATION

To obtain feedback on how well the revised laboratory activities are being received by students, a multiple approach to obtain feedback from students. A group of students was selected to take part in entering into an online journal of their experience as they worked through all the 5 activities. The students were also periodically interviewed by an impartial third-party staff member, namely an education advisor from the Polytechnic. Upon the conclusion of the activities, a survey was conducted for all 60 students in the program.

Overall, over 80% of respondents indicated that they understand the usefulness of teamwork, communication and thinking skills in their profession. 63% of respondents found the lessons more interesting with the re-designed activities, and likewise 61% respondents indicated they participated more actively in their lessons. 81% of respondents also replied that they now better understand the relationship between this module and other modules. This is broadly supported by the students' journal entries who commented that critical thinking skills were being explicitly assessed. Others reported on the benefits of role-playing in shaping understanding of teamwork, and usefulness of integrative-type of questions in linking chemical reaction engineering to other modules.

Lastly is the observation made by the author on his interactions with the students during the laboratory sessions. Overall, it is observed that all students are more forthcoming in "volunteering" an answer, and that is most cases, all members of the group will actively participate during debrief. Free-riding among students were nearly non-existent as all members are forced to take part in the group discussions. Complaints about group members not participating in the pre-experiment discussions were drastically reduced. There were still occasionally but rare (like one in 25 groups) that some free-riding exists in post-experiment report writing effort, and the team is now considering utilizing peer-assessment to discourage such behaviour.

SOME PERSONAL REFLECTIONS

The use of a pilot module like *Chemical Reaction Engineering* is important as it provided the author with first-hand experience how to go about executing the necessary revamp. The result can serve as a useful template to illustrate how the infusion of various soft skills, in the polytechnic's context, can be achieved in practice. Through numerous reworking of the design of the student guide and laboratory manual, the author was able to internalize the CDIO requirements and it serves to allay the initial fear of an increased curriculum hours that followed such revamp. It also helped to build confidence in how to effectively assess effectiveness of non-technical skills such as communication and teamwork.

Through the revamp effort, the author is convinced that it is not adequate to cover the learning of soft skills such as oral communication, report writing and presentation, only in standalone modules. Students still communicated poorly or wrote badly despite the numerous assignments to hand in. Others, such as teamwork and critical thinking, although stressed in the curriculum, were not effectively covered in the various core chemical engineering modules. Often students are assumed to somehow "get it"; for example, how to think critically after working through several tutorial questions, or able to work in teams after assigning them in groups for a given assignment or laboratory experiment.

Next is the mindset change that occurred on the use of pilot plants and workspaces. It was initially thought that new pilot plants as well as workspaces may be required to train students in these "new" skills of teamwork, communication, etc. On deeper analysis, such doubts were build on the traditional approach to teaching and training in which many experiments and laboratory activities were designed pretty much to prove the theories taught in classrooms. With the revamp effort calling for a "new" approach to teaching and training, it becomes a natural extension of the thinking process that there needs to have new facilities for new training. The result from the revamp of *Chemical Reaction Engineering* demonstrated conclusively that no additional workspaces are required. What is more important is how to weave into the existing laboratory sessions the application of the various soft skills.

The author also finds that working one-to-one with an education advisor is very effective at eliciting the 'hidden' or implied learning objectives desired by the module coordinator but not verbalised satisfactorily in written form in the specific learning objectives. Probing questions from the education advisor can help the module coordinator crystallize the rationale behind a stated learning objective, the revision of which can lead to a much clearer learning outcome. It becomes apparent that one should write learning outcomes in clear and appropriate terms.

Lastly, using a competency-based approach in assessment of intended learning outcome can help promote clearer and creative thinking in curriculum redesign, especially in terms of integrating various other CDIO skills as well as new developments such as green engineering, biofuels, etc. This will be elaborated in greater detail in next section.

FOLLOW-UP ACTIONS AND CHALLENGES

While one can discern from the above that integration of soft skills can be added onto existing laboratory sessions without incurring additional curriculum hours, more time is indeed required to conduct a more comprehensive assessment. There is also a very real increase in manpower: each of the *Chemical Reaction Engineering* experiments requires two lecturers to be deployed full-time for the entire 3-hour duration of the session.

On the assessment design, it can be contemplated that assessment of individual contribution to report submission be carried out. The current practice was based on a group effort with everyone in the group given the same report marks. It is a common practice among students that, to “optimize” the available time (real or perceived), they are inclined to share out the workload, say by dividing among 4 students 8 questions, each attempting 2 questions and then merely join together each other’s contribution for the submission. There is no attempt on their part to understand what the others had put together. Apart from that, the issue of “free-riding” can still arise. There can be a member of the group who had decided to take a back seat now that report writing is not being assessed on an individual basis. The author would like to consider introducing peer assessment into report assessment. Thus, another challenge is to encourage team-working in preparing the written report. Peer assessment would probably be the method of choice to assess individual contribution.

With the experience gained, the author will be proceeding to share his learning experiences with other lecturers with a view of helping them integrate the relevant CDIO skills into their respective modules. Several sharing sessions and a workshop had been conducted, as well as one-to-one coaching sessions. Work is in progress to roll out additional ‘CDIO-enabled’ modules covering at least 5-6 more modules from Year-1 through to Year-3.

Lastly, there remained the challenge of how to integrate more such soft skills into other instruction medium such as lectures, tutorials and assignments. More demanding are the lectures and/or tutorials, due to the large class sizes (60 or more students in the case of lectures and up to 40 students during tutorials). The team is contemplating to use the Bhopal tragedy as a case study to illustrate the impact of engineering design on society and the environment, and to touch on the questions of ethics as well. The Bhopal case study is also useful to in introducing the concept of green engineering as part of sustainable development, whereby an alternative synthesis pathway can avoid the production of harmful chemical intermediate altogether. The recent debate on biofuels is another topic rich in context for incorporation into the module to actively engage students in appreciating contradictory perspectives and understanding the responsibilities of chemical engineers to society.

CONCLUSIONS

At the time of this paper, two cohorts of students had completed the modules. Preliminary data for the second cohort indicate similar learning experience compared to the firs cohort, although the data for the second cohort seemed to reveal less satisfaction with the curriculum revamp. A small portion of these students do not appear to appreciate the importance of soft skills despite having completed the module. This could be due to the lower academic achievement of the second cohort, who adopted a rather indifferent attitude during lessons. This observation points to the difficulty of comparing the same laboratory design and assessment across cohorts of differing academic ability. Nonetheless, the results are encouraging enough for the team to continue fine-tuning the laboratory activities and their related assessment schemes for the benefit of the majority of students.

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Biographical Information

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