SUSTAINING CURRICULUM INNOVATION: THE DIPLOMA IN CHEMICAL ENGINEERING EXPERIENCE

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ABSTRACT

Curriculum innovation can be a long and challenging process in which a variety of conflicting interests and constraints have to be thoughtfully negotiated and addressed. It may take a number of years before the beneficial results of the desired curriculum change become evident. Adopting the CDIO Engineering Education Framework proved to be no exception. This paper details a major curriculum innovation for the Diploma in Chemical Engineering at Singapore Polytechnic in its journey to integrate CDIO into the three-year course program.

The entire course structure of the chemical engineering curriculum was completely revamped to include systematic teaching of skills in conceiving, designing, implementing and operating as well as other selected CDIO skills, such as Interpersonal Skills (teamwork and communication), Personal and Professional Skills and Attributes, etc. This was achieved through a combination of structural curriculum changes, including introduction of new modules, integration and removal of existing modules. The outcome is a more efficient and integrated curriculum format that clearly incorporates appropriate learning outcomes for both technical content areas and CDIO skills.

Using the principles of an aligned curriculum, we identified the most appropriate pedagogic approaches to meet these learning outcomes, wherever appropriate, through an active and experiential learning context. This involved a careful analysis of module content and the learning opportunities they offered, and infusing CDIO skills that would naturally support the learning of technical subject content. The curriculum development planning cycle was completed through establishment of an assessment approach calibrated to the learning outcomes.

The paper firstly outlines the key phases of the CDIO implementation. This is followed by a detailed discussion of our sustained approach to infuse various CDIO skills into laboratory sessions of selected core chemical engineering modules. The final section presents main findings from a wide range of evaluation data collected over the past 2 years, identifies the significant learning experiences as well as the planned action for sustaining and enhancing the success of the innovation in future.

KEYWORDS

Chemical Engineering, CDIO Skills, Curriculum Integration, Program Evaluation

INTRODUCTION

The Diploma in Chemical Engineering at Singapore Polytechnic embarked on a journey to revise and reorganize - ‘revamp’ - its curriculum using the CDIO Framework beginning late 2006. After around one year of preparation, a revised curriculum was rolled out in April 2008 for the Academic Year (AY) 2008. A full description of the overall approach taken at the commencement of the revamp effort and challenges encountered have been previously documented elsewhere [1], [2].

Broadly, the curriculum revamp effort can be viewed as a consisting of a 2-prong approach that resulted in an integrated curriculum delivered via an active learning environment:

(1) Integrating various soft skills such as teamwork, communication, critical thinking, etc (abbreviated as CDIO skills for the purpose of this paper) to provide a more holistic approach to engineering education where students get to practice technical skills alongside the various soft skills. This is largely achieved through systematic infusion of the CDIO skills into carefully designed active learning activities in the laboratory sessions of selected core chemical engineering modules.
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(2) Integrating skills in conceiving, designing, implementing, and operating (abbreviated as C-D-I-O skills to distinguish from the abovementioned CDIO skills) an engineering product or system using chemical engineering principles. This involves specific changes in course structure whereby new modules are introduced through merging or removing existing overlapping or obsolete modules, and culminates in a more effective execution of the students’ final year (capstone) project.

The resultant new course structure is shown in Figure 1.

The implementation of the CDIO Framework into the chemical engineering curriculum can be framed in three broad phases as listed below:

Phase 1 (January 2007 to April 2008)

- Introduction of new module *Introduction to Chemical Engineering* in Year 1
- Introduction of small-scale Design-Build Experience(s) into suitable module(s)
- Infusion of selected CDIO skills (e.g., Teamwork, Communication, Critical Thinking) into a pilot module *Chemical Reaction Engineering* in Year 2
- Development of a new module, *Product Design & Development* (PDD) for Year 2

Phase 2 (2008 to 2010)

- Infusion of Phase 1 CDIO skills (i.e. Teamwork, Communication, Personal Skills and Attitudes) into more modules across all three years of study
- Infusion of new CDIO skills (e.g., Experimentation & Knowledge Discovery, System Thinking) into selected modules
- Introduction of new module *Product Design & Development* in Year 2 to expose students to the C-D-I-O skills in Conceiving an engineering solution to an identified need, followed by Designing, Implementing and Operating the engineering solution as a Year 3 *Final Year Project*
- Re-design of assessment scheme of Year 3 *Final Year Project*, to cater for the different project genres that students may undertake

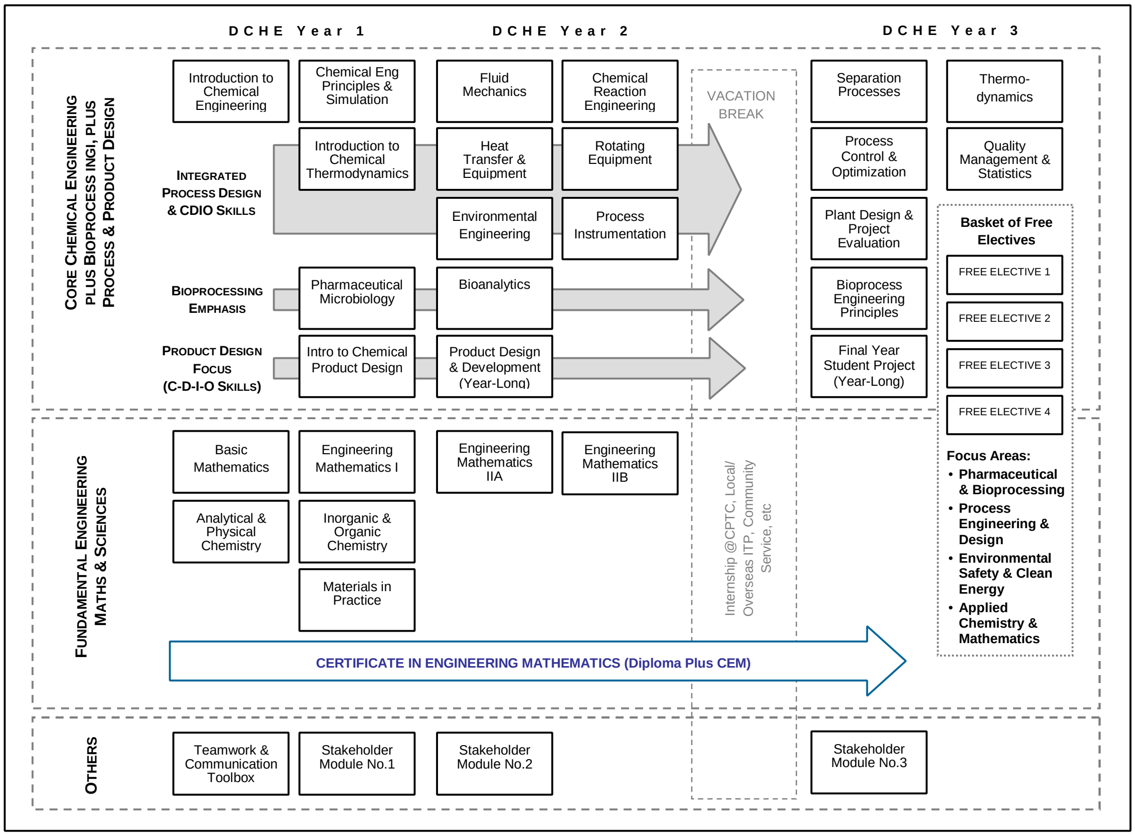

Figure 1. Revised Course Structure for Diploma in Chemical Engineering

Phase 3 (to start in 2010)

- Infusion of Phase 2 CDIO skills into suitable modules across all three years of study to completely integrate the skills
- Development work for a new module in Year 1, that includes design thinking and introduction to chemical product design, as well as revamping Year 2 PDD to include concepts of product Lifecycle Analysis and Sustainable Development
- Infusion of CDIO skills External & Societal Context, and other remaining skills into suitable modules.

The revamp effort started in early January 2007 following the polytechnic's adoption of CDIO for all its engineering programs. Phase 1 was completed with the roll-out of the CDIO initiative for the Diploma in Chemical Engineering in AY 2008. The specific work carried out for the Diploma in Chemical Engineering during this phase was extensively covered in past CDIO proceedings [3]. [4], [5].

Phase 2 is still in progress at the time of this paper. The "boundaries" between the phases are in fact somewhat arbitrary and often blurred in practice. From the onset, we recognized the importance of not being too prescriptive, encouraging module coordinators to try out integration of other skills as deemed relevant in their respective modules. Hence, in practice, there are overlaps in skill coverage, as compared to the three broad phases identified above.

Table 1
CDIO Skills infused into modules in Diploma in Chemical Engineering

Process Instrumentation (Year 2, Stage A)	CDIO Skills Infused	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5
	Teamwork			✓		
	Communication			✓		✓
	Critical Thinking	✓	✓		✓	
	Manage Learning			✓		
Introduction to Chemical Engineering (Year 1, Stage 1A only)	CDIO Skills Infused	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5
	Teamwork				✓	✓
	Communication			✓	✓	✓
	Critical Thinking	✓	✓		✓	
	Different Perspectives			✓		
	Manage Learning	✓	✓		✓	✓
Introduction to Chemical Thermodynamics (Year 1, Stage B)	CDIO Skills Infused	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5
	Teamwork	✓			✓	
	Communication					
	Critical Thinking		✓		✓	✓
	Manage Learning	✓		✓	✓	
Chemical Engineering Principles & Simulation (Year 1, Stage A)	CDIO Skills Infused	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5
	Teamwork	✓				
	Communication			✓		
	Critical Thinking		✓	✓	✓	
	Knowledge Discovery	✓				
	Manage Learning			✓		✓
Heat Transfer & Equipment (Year 2, Stage A)	CDIO Skills Infused	Lab 1	Lab 2	Lab 3	Lab 4	
	Teamwork	✓		✓	✓	
	Communication		✓	✓		
	Engineering Reasoning & Problem Solving	✓	✓		✓	
	Experimental Enquiry		✓			
	Manage Learning			✓	✓	
Chemical Reaction Engineering (Year 2, Stage B)	CDIO Skills Infused	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5
	Teamwork	✓			✓	
	Communication	✓		✓	✓	✓
	Critical Thinking		✓	✓		
	Different Perspectives				✓	
	Manage Learning		✓			✓
Rotating Equipment (Year 2, Stage B)	CDIO Skills Infused	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5
	Communication	✓		✓		
	Engineering Reasoning	✓	✓			
	Experimental Enquiry				✓	
	System Thinking		✓			✓
	Manage Learning			✓		
Mass Transfer in Unit Operations A (Year 3, Stage A) - To be merged with Mass Transfer in Unit Operations B to become Separation Processes	CDIO Skills Infused	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5
	Teamwork		✓	✓		✓
	Communication	✓		✓	✓	
	Critical Thinking	✓	✓	✓	✓	✓
	Different Perspectives	✓			✓	
	Manage Learning		✓			
	Ethics	✓				
Bioanalytics (Year 2, Stage B)	CDIO Skills Infused	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5
	Experimental Enquiry					✓
	Manage Learning					✓
Membrane Science & Technology (Year 3, Free Elective)	CDIO Skills Infused	Lab 1	Lab 2	Lab 3	Lab 4	
	Teamwork			✓		
	Communication		✓	✓	✓	
	Experimental Enquiry			✓		
	Critical Thinking		✓			
	Manage Learning	✓			✓	

The main focus of this paper is on the first part of the revamp effort, which is to integrate CDIO skills such as teamwork, communication, personal and professional skills and attitudes, etc, into the curriculum. The bulk of the work on the second part of the revamp effort, that of integrating C-D-I-O skills (i.e. conceiving, designing, implementing and operating an engineering system or product), is still in progress and a more detailed coverage is deferred to a later paper.

The modules in the Diploma in Chemical Engineering with CDIO skills integrated into lab activities are summarised in Table 1. In total, ten modules had their laboratory activities "CDIO-enabled" by the time we arrived at Phase 2. Of these, three modules are from Year 1, five modules from Year 2 and two modules from Year 3.

THE APPROACH TO SUSTAINABLE CURRICULUM RE-DESIGN

Arising from the revamp efforts, a "model" gradually evolved that paved the way for other faculty to carry out similar curriculum development, using what we came to refer as "the chemical engineering way" to integrate CDIO skills into students' learning experiences.

An important starting point was the identification of the key underpinning knowledge for various CDIO skills such as teamwork, communication, personal and professional skills, experimentation and knowledge discovery, etc, based on the original CDIO syllabus [6], customizing where appropriate for diploma-level education. We then re-wrote the module syllabi in terms of clear learning outcomes, calibrated to the identified level of underpinning knowledge. Training classes were conducted to ensure that all lecturers understood the underpinning knowledge and related learning outcomes. Relevant examples in chemical engineering were used so that all lecturers can clearly contextualize the desired CDIO skills to his/her respective lesson plans.

CDIO Skills: Introduce & Teach				CDIO Skills: Utilize	
Stage 1A	Stage 1B	Stage 2A	Stage 2B	Stage 3A	Stage 3B
Introduction to Chemical Engineering	N.A.	Engineering Mathematics IIA	Engineering Mathematics IIB	Process Control & Optimization	
Basic Mathematics	Engineering Mathematics I	Fluid Mechanics	Rotating Equipment	Separation Processes I	Separation Processes II
Analytical & Physical Chemistry	Inorganic & Organic Chemistry	Heat Transfer & Equipment	Chemical Reaction Engineering	Thermodynamics	
Materials in Practice	Pharmaceutical Microbiology	Process Instrumentation	Environmental Engineering	Project (CDIO DBE)	Project (CDIO DBE)
Chemical Process Principles & Simulation	Introduction to Chem Thermodynamics	Plant Safety & Loss Prevention	N.A.	Free Elective 1	Free Elective 3
N.A.	Intro to Chemical Product Design	Product Design and Development	Product Design and Development (cont'd)	Free Elective 2	Free Elective 4
Stakeholder Module No.1	Teamwork and Communication Toolbox	N.A.	Stakeholder Module No. 2	N.A.	Stakeholder Module No. 3
		Industrial Training Programme	Industrial Training Programme		

Figure 2. Integrating CDIO skills across a three-year curriculum

All module syllabi were moderated to ensure clarity of learning outcomes, through a one-day workshop in which lecturers were split into 4 groups, and each group was given 4 or 5 module syllabi of related subjects to scrutinize. The module coordinator facilitated as necessary to deal with any ambiguity, and modifications were made to the learning outcomes where necessary.

The result is a more robust syllabus for each module, and enhanced understanding among lecturers of what their colleagues are teaching, and the relationship of the modules to each other.

We adapted the ITU (introduce, teach, utilize) concept [7] to systematically introduce various CDIO skills into laboratory sessions of selected core chemical engineering modules. The general approach taken is illustrated in Figure 2, which shows the integration of teamwork and communication skills across the entire diploma's three-year duration. The aim is to first introduce and teach students specific skills in Year 1, which are then extensively practiced in Year 2. By Year 3 they are expected to be able utilize the skills where appropriate and display transfer.

In revamping the curriculum, we used the student-centered Triangle of Course Design [8] as shown in Figure 3. The module coordinators, together with the Senior Education Advisor from the Department of Educational Development (EDU), reviewed all the module learning outcomes to verify appropriateness and clarity.

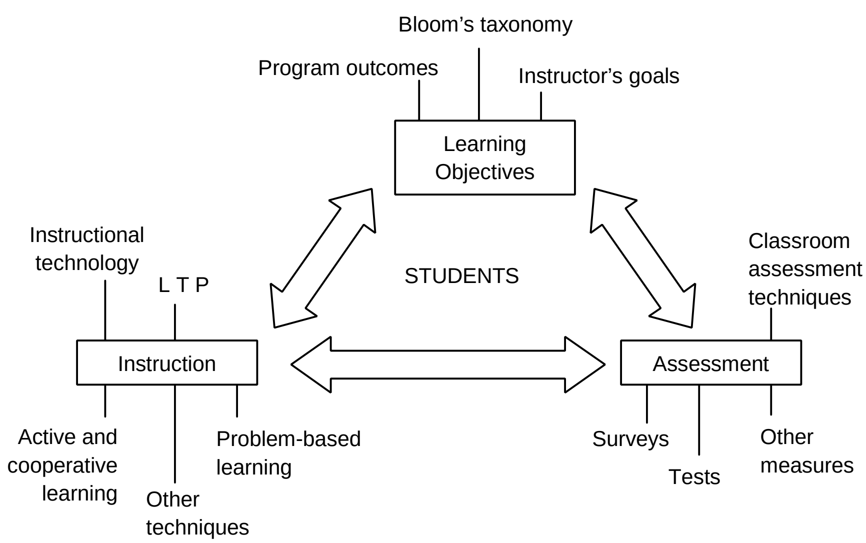

Figure 3. Student-centred approach to curriculum design

At the end of each semester, extensive program evaluation was carried out, with the help of EDU staff. The scope of the evaluation varies from year to year, depending on the objective of integrating CDIO at that year of study. For example, Year 1 focused on student awareness of the usefulness of the skills; Year 2 on the usefulness of the activities in skill development, and; Year 3 on application and transfer.

Example of Sustaining Curriculum Re-design: Teamwork and Communication

Our students have to complete many hands-on sessions in the laboratories over their three years of study. Hence laboratory sessions offered an authentic environment to infuse various CDIO skills. We therefore decided to integrate teamwork and communication right from Year 1. Not only are these two skills familiar to both faculty and students, they are also the easiest to integrate. Experiments were contextualized to simulate real-world working environments whereby students are required to work in teams and conduct experiments using various pilot plants.

In that way students get to practice teamwork and communication while at the same time learning the technical aspects of the discipline of chemical engineering. The approach adopted is illustrated using teamwork and communication as the main examples. The underpinning knowledge for teamwork, for example, is shown in Table 2.

Table 2
Underpinning Knowledge for Teamwork

Form Effective Teams • The key components/attributes of successful teams (e.g., shared vision/goals, unified commitment, principled leadership, competent members, a collaborative climate, standards of excellence etc). How these components/attributes result in effective teamwork in a range of situations (e.g., work team, social team, family. The notion of synergy, e.g., the performance of an effective team is more than the sum of the individual's competences within it. • The process of team formation (e.g., forming, storming, norming, performing). How specific challenges typically present at each stage and what can be done to help the team to progress to achieve high performance. • The concept of team role (e.g., Belbin) which suggests that different personalities offer both strengths and 'allowable' weaknesses to a teams' performance. The implications of different team roles to the composition, functions team and performance (e.g., need for both coverage of the range of team roles as well as balance to ensure all functions are well met. • The different ways in which the strengths and weaknesses of a team can be appraised and improved (e.g., questionnaires, observation, facilitation, etc)
Manage and Participate in Teams • The importance of: a) appropriate goal setting (e.g., clear, shared, meaningful, etc) and b) structured and achievable agenda for effective teamwork. How to set goals and prepare agendas for team meetings. • The importance of ground-rules (e.g., ways of working and conduct, etc) in effective team-working. How to identify appropriate ground-rules and implement them effectively. • The basic communication skills, core practices and process tools of conducting facilitation (e.g., staying neutral, listening, surfacing and testing assumptions, focusing, summarizing, using tools for generating, organizing and managing information, etc) • The basic conflict resolution strategies (e.g., win-win, negotiated give and take, etc). How to use these effectively • How participation in a range of team contexts (e.g., in project teams, ECA teams, school dept teams, etc), and reflecting on these experience, helps to develop both understanding of personal strengths and weaknesses in relation to different team roles, as well as practical competence as a team player.

When the students joined the program in Year 1, the majority of them do not know each other, having come from different parts of Singapore. We took advantage of the fact that we customarily do not start laboratory activities right away at the beginning of a new semester. The first week was used for safety briefing, and to allow time for student to familiarize with the tasks at hand to make better preparation, starting the laboratory sessions only on week 2. Hence we decided to use the first week of the lab sessions to familiarize students with the underpinning knowledge of teamwork. After the usual safety briefing, the students were then introduced to the CDIO framework and briefed on the components of teamwork based on the underpinning knowledge that was developed.

The students were then formed into groups by the lecturer and a simple exercise was carried out whereby they had to complete the following:

- Identify their respective strengths and weaknesses as team players
- Derive team goals and set ground rules for effective team-working
- Identify strategies for dealing with potential team problems (e.g., resolving conflict, etc).

Often both teamwork and communications are introduced into the same activity. Selected examples of activities designed across all three years are shown in Table 3.

Table 3
Integrating CDIO Skills: Teamwork & Communication

Year 1 Introduction to Chemical Engineering	Year 2 Chemical Reaction Engineering	Year 3 Separation Processes
In this activity, students need to collect water samples from various sources around campus and perform quality tests. They are divided into a Lab Technician, an Assistant Engineer and the rest Process Technicians. The Process Technicians are to collect water samples while the Lab Tech performs the tests on samples collected. The Process Technicians are to communicate with the Assistant Engineer via walkie-talkie at various 'checkpoints'. The Assistant Engineer records all communications on a log sheet. One of the locations is deliberately chosen to be out of range of the walkie-talkie. A debrief was conducted.	In this activity, students are to decide on various roles include a Supervisor, Panelman, Senior Technician and Technician, in starting up a chemical reactor pilot plant. The Senior Technician has to fill in a communication log sheet detailing major milestone in the activity. The lecturer plays the role of the Plant Manager who at random intervals ask for updates from the Supervisor, and on several occasions the Supervisor needs to confer with the Senior Technician to obtain the necessary information from the log sheet.	In this activity, students are informed that they are part of a team in a company specializing in packing materials for separation processes and the task is to carry out tests of the company's packings. They are asked to form a team and one of them is to deliver an oral presentation to a potential customer on how the testing is being performed. They also need to submit a Technical Report detailing the work performed.

Throughout the entire three years, various communication channels are introduced to the students in over twenty laboratory sessions, including writing technical memo, writing technical report, writing formal (academic) report, completing a communication log sheet, delivery a stand-up oral presentation, communication using walkie-talkie, and delivering PowerPoint presentations.

Teamwork and communication are also promoted through an integrated system of Q&A sessions. Students are required to attend a vivo session before starting an experiment as well as debrief at the conclusion of an experiment. Broadly, the questions can be classified into the following three categories as shown in Table 4.

Table 4
Questions used during pre- and post-experiment assessment

Category of Question	Marks Allocation	Example Questions
Different questions for each member, to be answered by individual students	Individual	• Theoretical understanding of underpinning sciences
Same question directed at all members of the group, each student is expected to provide a different answer	Individual	• Hazard analysis, consequence and safety precaution required • Sources of error and impact on experimental result • Suggestion for improvement
Group questions directed all members of the group whereby students discuss among themselves and each takes turn to answer	Group	• Analysis of experimental results • Engineering reasoning and problem-solving

Individual questions are designed to promote camaraderie among students, where the student who is stronger conceptually is encouraged to render assistance to the weaker ones. They also serve to reduce students free-riding, as everyone is expected to answer some questions at one time or another. Students are encouraged to discuss in their respective groups prior to the vivo, and time was also given for them to discuss prior to debrief.

Table 5
Integrating CDIO Skills: Holding Multiple Perspective

Year 1 Introduction to Chemical Engineering	Year 2 Chemical Reaction Engineering	Year 3 Separation Processes
In this activity, students are required to study the relevant section of a pharmaceutical pilot plant where a new back-up pump is to be purchased, installed and commissioned. They are required to prepare 2 separate memos (one to Purchasing Department, and one to Operations Department) related to the task. In one of the questions, there were asked to identify one of the most important issue from the perspective of the following persons: (a) Operations Manager, (b), Purchasing Officer, (c) Maintenance Manager, and (d) Financial Controller.	In this activity, students are required to operate on a chemical reactor pilot plant. At the end of the lab session, they were presented with a typical engineering problem of plant modification work (namely installation of a high temperature alarm). Each student was given a “game card” detailing the role that he/she had to play, e.g. as a Finance Executive, Maintenance Engineer, Safety Officer, etc. The lecturer, acting as the Plant Engineer who suggested the modification work, starts the discussion, and students are asked to identify which perspective the other person is coming from.	In this activity, students took the role as members from the Engineering Department, and are tasked with managing a multi-disciplinary project on a major plant modification. They were given a minutes of meeting attended by their supervisor, which records comments made by various team members comprising representatives from Sales & Marketing, Maintenance, Safety, etc. They are required to “make sense” of the comments from the minutes of meeting and suggest how the differences in opinion can be resolved.

Integrating Other CDIO Skills

In an already packed curriculum, there is always a challenge in integrating additional skill components. To address this challenge we looked for ways to expose students to other skills by embedding them in suitable practicals in a similar manner employed for teamwork and communication. For example, the ability to 'hold multiple perspectives', while not explicitly taught in classroom lectures, was contextually embedded in laboratory activities over the three years of study (see Table 5).

Table 6
Efforts at Infusing C-D-I-O Skills in DBE across all three years of study

<table>
<tr><th>Year 1 Introduction to Chemical Engineering
(Rolled out in AY2008)</th><th>Year 2 Chemical Reaction Engineering
(Existing, Revamped)</th><th>Year 3
Final Year Project
(Existing)</th></tr>
<tr><td>Introduces student to early DBE, requiring them to produce a DIY Water Filter Kit. Students are to select 3 out of 4 given materials (namely pebbles, corals, sand and crushed granite) for the filter media. They are also required to price their product, given basic costs of the raw materials.</td><td>Students are required fabricate a simple chemical reactor using prescribed materials, to achieve a specified production rate using saponification to produce a product of specified purity. Students need to make a decision on the reactor diameter against the reactor length.</td><td rowspan="3">Enables application and integration of the knowledge and skills acquired throughout the course to solve practical problems involving plant and equipment design, experimental analysis, process simulation or applied R&D.

Students work in groups of 3 under the supervision of a lecturer. Projects can be initiated by students, proposed by lecturers, or in collaboration with industrial partners. Assessment is by in-course assessment and project seminar.

A revamp work is now in progress to introduce different assessment criteria for projects of different genre.</td></tr>
<tr><td>Year 1 Introduction to Chemical Product Design
(In Progress, to roll out in AY2011)</td><td>Year 2 Product Design & Development
(Rolled out in AY2009)</td></tr>
<tr><td>Module Aim: Provides students with basic understanding in design methodology for chemical products such as ink, paint, chocolate, skin lotion, etc. Students will learn the tools of design thinking, perform market research to identify consumers' needs, analyze and interpret survey results, as well as apply idea creation techniques and translate consumers' needs into chemical product design specifications. Through various active learning experiences, students will learn to work effectively in teams and make effective oral and written communications on their product design proposals.</td><td>This module is now undergoing revision after its introduction in AY2009. Students will learn about basic concepts in product life cycle analysis, marketing techniques, cost estimation, and the integration between product and process design. Students will also apply critical and creative thinking; and following up on their ideation in Year 1, students will fine-tune their product proposals and the development of business proposal. The purpose is to encourage more students to propose their own projects for Year 3.</td></tr>
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Design Build Experience and C-D-I-O Skills

All Diploma in Chemical Engineering students are required to complete a *Final Year Project* in Year 3. This is the opportunity for them to get exposed to a Design Build Experience (DBE) in applying knowledge gained in the discipline of chemical engineering to solve various engineering problems. Students are allocated a total of 120 curriculum hours for their *Final Year Project*. The plan of the infusion of C-D-I-O skills is summarized in Table 6.

As we recognized the importance of exposing students early in their course of study to suitable design-build experiences, we decided to add one DBE each in Year 1 and Year 2. The objective of these early DBEs is to expose students to uncertainty, awareness of evaluating selection and making trade-offs in selecting a solution to a given problem. The Year 1 DBE was introduced as part of the requirements in the module *Introduction to Chemical Engineering*, while the Year 2 DBE was introduced in the module *Chemical Reaction Engineering*.
As mentioned in the previous section, the students in AY2009 who completed their Year 3 *Final Year Project* had no formal training in project work. To better support our students' ability to conceive, design, implement and operate an engineering system derived from application of chemical engineering principles, we introduced a new module entitled *Product Design and Development* (PDD) for the Year 2 students in AY2009 [9]. We hoped that through this new module, coupled with the mini design-build-experiences gained from *Introduction to Chemical Engineering* and *Chemical Reaction Engineering*, will better prepare our students to work on their *Final Year Project*.

Lastly, as also shown in Table 6, we planned to introduce a new module in Year 1 (tentatively entitled *Introduction to Chemical Product Design*) to equip students with the necessary ideation skills using the design thinking process made popular by IDEO CEO Tim Brown [10]. This work will be presented in future papers. Using the approach outlined in previous section (see Figure 2), we plan to integrate the C-D-I-O skills into the chemical engineering curriculum by AY2011, as shown in Figure 4.

C-D-I-O Skills: Conceive-Design-Implement-Operate

Stage 1A	Stage 1B	Stage 2A	Stage 2B	Stage 3A	Stage 3B
Introduction to Chemical Engineering	N.A.	Engineering Mathematics IIA	Engineering Mathematics IIB	Process Control & Optimization	
Basic Mathematics	Engineering Mathematics I	Fluid Mechanics	Rotating Equipment	Separation Processes I	Separation Processes II
Analytical & Physical Chemistry	Inorganic & Organic Chemistry	Heat Transfer & Equipment	Chemical Reaction Engineering	Thermodynamics	
Materials in Practice	Pharmaceutical Microbiology	Process Instrumentation	Environmental Engineering	Project (CDIO DBE)	Project (CDIO DBE)
Chemical Process Principles & Simulation	Introduction to Chem Thermodynamics	Plant Safety & Loss Prevention	N.A.	Free Elective 1	Free Elective 3
N.A.	Intro to Chemical Product Design	Product Design and Development	Product Design and Development (cont'd)	Free Elective 2	Free Elective 4
Stakeholder Module No.1	Teamwork and Communication Toolbox	N.A.	Stakeholder Module No. 2	N.A.	Stakeholder Module No. 3
		Industrial Training Programme	Industrial Training Programme		

Figure 4. Integrating C-D-I-O Skills into 3-year chemical engineering program

EVALUATION: STUDENT LEARNING EXPERIENCE

Program evaluation has been a central part of the CDIO curriculum initiative. The purpose and approach of the evaluation is consistent with that identified by Kemmis [11]:

> Evaluation is the process of delineating, obtaining and providing information useful for making decisions and judgments about educational programs and curriculum. (p.117)

A combination of methods is employed:

- Student "co-participants", a term borrowed from Lincoln [12], who provide ongoing feedback via online journal (blog) entries and focus group discussions (typically 2 per class)
- Survey questionnaire for all students in designated classes
- Lecturer reflection and feedback
- Lesson observation.

Methods are administered by independent third party EDU education advisors. The student co-participants were selected by the respective module coordinators. Other than Year 1 students, which were picked at random, other students from Year 2 and Year 3 were selected not for their academic prowess, but rather on their willingness to contribute to the CDIO program evaluation. All student co-participants are required to stay with the program evaluation for the entire duration during their study and took part in the focus group discussions. Staff from EDU briefed the students on the objective of the CDIO program evaluation.

For the survey, the questionnaire employed a 5-point Likert-Scale to explore aspects of the students learning experiences relating to CDIO skills (e.g., 1 – Strongly Disagree, D – Disagree, N – Neutral, A – Agree, and SA – Strongly Agree). Surveys for Phase 1 activities was restricted to gauging student learning experience for the new Year 1 module *Introduction to Chemical Engineering*, and CDIO-enabled Year 2 module *Chemical Reaction Engineering* and *Rotating Equipment*. The results were positive and encouraging [4], [5]. For Phase 2, with more modules to choose from, we surveyed the selected core modules as listed in Table 7. The scope of the survey was much wider and to avoid "survey fatigue" among students not every module with CDIO-type activities (as seen in Table 1) was surveyed.

Table 7
Diploma in Chemical Engineering: Modules surveyed for student experience (S1 AY2009)

Year & Stage	Module Name	CDIO-Enabled?	No. of Students	No (and %). of Respondents
1A, 1B	*Introduction to Chemical Engineering*	YES	60+60	82 (68%)
1A	*Chemical Process Principles & Simulation*	YES	60	36 (60%)
1B	*Introduction to Chemical Thermodynamics*	YES	60	46 (77%)
2A	*Heat Transfer & Equipment*	YES	60	30 (50%)
2B	*Chemical Reaction Engineering*	YES	60	42 (70%)
2B	*Rotating Equipment*	YES	60	59 (98%)
3A	*Mass Transfer in Unit Operations A*	YES	60	32 (53%)
3B	*Mass Transfer in Unit Operations B*	NO	60	39 (65%)

Consistent with the Framework in Figure 2, Year 1 students in AY2009 were surveyed primarily on their learning experience in these CDIO-enabled modules. We focused mainly on the student's awareness that such skills had been explicitly integrated into the learning experience. While skills such as teamwork and communications were taught in secondary schools, this is their first encounter where they are specifically contextualized to a professional discipline.

Students in Year 2 are broadly surveyed on their understanding and application of the skills, based on laboratory activities with explicit CDIO requirements. These Year 2 students were briefly exposed to CDIO skills in the previous year (i.e. AY2008) in the module *Introduction to Chemical Engineering* when the module was first introduced. Previously the modules *Chemical Process Principles & Simulation* and *Introduction to Chemical Thermodynamics* had not been CDIO-enabled.

Students in Year 3 are assessed on their application of CDIO skills. These students (both stages) completed two CDIO-enabled modules in their second year of study, namely *Chemical Reaction Engineering* and *Rotating Equipment* in AY2008. It is worthwhile to note that these students conducted their *Final Year Project* in AY2009 without the benefits of the new module *Product Design & Development* that was introduced in Year 2 in AY2009.

The results are interesting in a number of aspects. Year 1 students from Stage A typically gave lower scores of their learning experience compared with Year 1 Stage B students: 10-15% of Stage 1A students rated "D" or "SD" many of their learning experiences, compared to 5-10% from Stage 1B students. This largely reflected the academic ability of the students: academically stronger ones are grouped into Stage 1B whereas the weaker ones are in Stage 1A. Notwithstanding the above, there is consistency among both stages of students in 2 areas: the ability to think critically, and confidence in delivering oral presentation. Students in Year 2 showed markedly smaller differences in ratings between the 2 stages. However, the same concerns over critical thinking and delivering oral presentation arose once again among the Year 2 students.

The Year 3 survey results are particularly interesting. As can be seen in Table 7, one cohort of students (Stage 3A) undertook laboratory sessions that had been CDIO-enabled (*Mass Transfer in Unit Operations A*), while the other (Stage 3B) went through another set of laboratory sessions for a module that is not CDIO-enabled (*Mass Transfer in Unit Operations A*). The results showed that both cohort of students are relative comfortable with utilizing these CDIO skills regardless of whether they were prompted or not. They were also more confident in applying the thinking process to solve engineering problems. We would like to infer that Stage B students have been able to transfer their learning from the second year learning experiences.

From the journal entries and focus group discussions, the first-year students from *Introduction to Chemical Engineering*, *Chemical Process Principles & Simulation* and *Introduction to Chemical Thermodynamics* were generally positive about their learning experiences, especially through the many experiments in the modules. The following student quotes reflect their experiences relating to thinking, teamwork and communication:

É I feel as though the more thinking I am put through, the better I am able to think

I felt that this experiment improved my teamwork, thinking and communication

However, in some cases negative experiences are reported. For example, one student wrote:

> I forgot what she taught   BUT I do remember that there isn't any interesting teaching methods that allows communication and team-working

From the journal entries and focus group discussions, the Year 2 students from *Heat Transfer & Equipment, Chemical Reaction Engineering* and *Fluid Mechanics B* generally felt that they were able to apply the skills learnt from the first year, as well as see connections between modules studied. It is apparent that most students have clear conceptions of what constitutes good communication and teamwork. However, student response in focus group discussions to the questions "What is good thinking?" and "Do your lecturers explicitly teach you to think?" reveal greater variation in experience (e.g., some feel that thinking is being explicitly taught but others do not). This seems to vary depending on the particular lecturer taking the class. As with the experience of Year 1 students, there appears to be significant variation based on the teacher taking the class.

The data for the third year students, *Mass Transfer in Unit Operations* A (CDIO) and *Mass Transfer in Unit Operations* B (non-CDIO) generally confirmed the questionnaire findings outlined above. Students in both groups felt that they were able to apply the various CDIO skills to their current experiments, pointing out that skills like thinking, managing learning, teamwork and communication are needed in most experiments.

CONTINUOUS IMPROVEMENT TO SUSTAIN CURRICULUM REVAMP: FUTURE DEVELOPMENTS

Experiences gained from the surveys and focus group discussions in AY2008 were used in the design of new activities for AY2009, as well as to revise the activities originally introduced in AY2008. For example, teamwork was not explicitly taught in the AY2008 curriculum. Our experience during the first year conducting these CDIO-enabled practicals convinced us that there is a real need to explicitly teach students about teamwork.

As teamwork and communications are often practiced together, we decided to revamp our communication modules alongside the teaching of teamwork. We engaged the assistance of lecturers from the School of Communication, Arts and Social Sciences to prepare a new 60-hr module *Teamwork and Communication Toolkit* to be introduced in AY2010. This module will be "twinned" with a core chemical engineering module *Introduction to Chemical Thermodynamics,* in terms of assignments for written and oral communications. Students will be required to submit a report, which will be graded for both technical content and adherence to good report writing skills. In addition, students will also be required to deliver a PowerPoint presentation based on one of their lab activities.

To further enhance students skills in a number of critical thinking skills (e.g., analysis, comparison and contrast, inference and interpretation and evaluation), the use of dynamic simulation of a chemical reaction plant is being utilized. At present few lecturers are teaching thinking explicitly, most are teaching it implicitly through activities that require students to use a range of thinking skills.

A pilot project is in progress to model students thinking as they work through problem-solving activities in the simulation. Apart from evaluating the usefulness of dynamic simulation in developing skill in critical thinking, we are interested in developing a domain-customized model of critical thinking (e.g., chemical engineering), which can be used by faculty in the explicit teaching of critical thinking.

Our journey to revamp the Diploma in Chemical Engineering curriculum using the CDIO framework is a rich and rewarding experience. It has been both timely and appropriate to meet the changing demands of the chemical engineering education that is taking place over the last 10 years. Our effort of the last 2 years to integrate the various CDIO skills appeared to be successful, as validated by the feedback received from students on their learning experience in CDIO-enabled modules. However, the journey is far from over. As noted above, there are still a number of significant changes that we plan to make to the curriculum over the next few years. The approach outlined in this paper will continue to form the foundation on which the curriculum revamp will be based.

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