CHEMICAL PRODUCT ENGINEERING USING CDIO ENHANCED WITH DESIGN THINKING

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ABSTRACT

The Diploma in Chemical Engineering (DCHE) of Singapore Polytechnic (SP) adopted the CDIO framework as the basis for its curriculum since 2007. In an earlier paper (presented at the 6th International CDIO Conference in 2010), the authors shared on the inclusion of a module *Product Design and Development* in Year 2 of the DCHE curriculum as a response to the emergence of chemical product engineering in the chemical engineering discipline.

This present paper is an update of work done since then. It briefly explains what design thinking (DT) is, and how it fits into the CDIO framework. It then explains the coverage of the new module *Introduction to Chemical Product Design* and how we customized the teaching of DT to meet the needs of chemical engineering. It shares the general outline of the syllabus and how it guides our approach in designing the various learning tasks in an integrated curriculum, including the use of reverse engineering.

It shares how we integrate the new module with existing modules *Product Design and Development* and *Final Year Project* to provide a seamless coverage of C-D-I-O skills across the diploma's 3-year curriculum; as well as important revisions made to the original *Product Design and Development* module.

The paper then discusses some challenges faced by the team and some approaches that we have taken to overcome these difficulties.

Lastly, we shares some learning points from this initiative, which at the time of this submission, had just completed its first pilot run. Ideas for furthering improving the teaching of this exciting subject in chemical engineering will also be presented.

(NOTE: Singapore Polytechnic uses the word "course" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called “courses”.)

Keywords: Chemical product engineering, CDIO, curriculum integration, design thinking

INTRODUCTION

As we moved into the new millennium, the chemical process industries, which include the petroleum, fine chemicals, pharmaceuticals and health, cosmetics, household care, agro and food, have been facing dramatic social, economic and technical challenges, on a global and local scale. Globalisation, advances in technology, sustainability of natural resources, etc had lead to the creation of new industries where chemical engineers are wanted. Recent chemical engineering graduates now found employment in industries that did not exist 10-20 years ago or did not until recently discover the usefulness and relevance of chemical engineers in their profession. New opportunities had opened up for chemical engineers in areas such as pharmaceuticals, biotechnology, nanotechnology, product development, and sustainable development. Henceforth the new concept of chemical product design and engineering had entered the vocabulary of chemical engineering. These challenges had been covered by one or both authors in separate papers [1, 2, 3].

In response to the above challenges, the Diploma in Chemical Engineering (DCHE) at Singapore Polytechnic (SP) had introduced chemical product design into its 3-year curriculum using the 4-step product design methodology for chemical engineering [4]. Integration of chemical product design into the curriculum follows the CDIO (Conceive-Design-Implement-Operate) framework (www.cdio.org) we adopted as the basis for a wider curriculum revamp effort that started in 2007 [1]. We had in mind the objective of getting more students to propose their own final year projects that are innovative and impactful, by applying what they learnt in chemical engineering. A new Year-2 module *Product Design and Development* (*PDD*) was introduced into the curriculum in Academic Year (AY) 2009. Ideation tools such as brainstorming and SCAMPER were introduced to support the "Conceive" phase of chemical product design. We also made changes to the project assessment scheme, the details of which were covered elsewhere [5]. We conducted student surveys and identified several areas that are of particular challenges to students [3]. One of the areas concerns better identification of user needs.

In our earlier work [2] we reported that we are looking at integrating design thinking (DT) into the DCHE curriculum. Design thinking is used by global consultancy company IDEO which has over 1000 patents since 1978 and has worked collaboratively with fortune 100 companies such as Microsoft, PepsiCo, Procter & Gamble and Steelcase. The DT approach focuses on 3 mutually supporting elements, namely that of user empathy, technical feasibility and business viability, as shown in Figure 1 below [6].

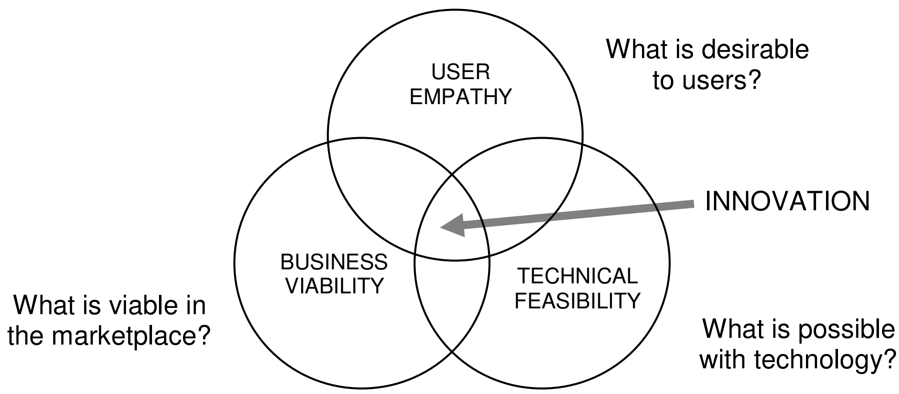


Figure 1: The Design Thinking Framework

With the release of the report of the Singapore Economic Strategies Committee in 2010, DT was noted as a key skill for a competitive workforce for the country [7]. We readily recognized that design thinking is the “missing link” that we can use to bridge the gap identified in earlier teaching of chemical product design. Tim Brown, the current CEO of IDEO, noted that [6]:

> The principles of design thinking turn out to be applicable to a wide range of organizations, not just to companies in search of new product offerings. A competent designer can always improve upon last year’s new widget, but an inter-disciplinary team of skilled designer thinkers is in a position to tackle more complex problems.

Key to the design thinking process was the user research that the students were tasked to do. As noted by Kumar and Whitney [8], DT is about “… looking at activities that surround the product, rather than getting reactions to the product (and related distribution, promotion and price) leads to breakthrough ideas that are grounded in how people are living.”

INTEGRATION OF DESIGN THINKING INTO CDIO FRAMEWORK

The emphasis of DT coverage in our curriculum is to complement the conceive-phase and design-phase of the CDIO framework, which in this case, is set in the context of CDIO for chemical product engineering. The infusion of DT with CDIO encourages students to propose innovative chemical products that are not only feasible technologically, but also viable economically, and in particular, desired by target consumers.

In SP, we are also interested in coming up with creative solutions that can help people in the bottom of the pyramid. As such, some design briefs (a DT term for problem statements) that are given to students focus on them deriving novel, low-cost, simple-technology chemical products that are well adapted for use by people in the bottom of the pyramid. In all, we believe that integration of DT with CDIO will provide students with authentic learning experience as envisaged in CDIO Standard 5 *Design-Implement Experiences*.

The integration approach we adopted is in line with SP’s approach to introduce DT into all diplomas, as part of the institution-wide initiative to bring Holistic Education to our students [9]. In our adaptation of DT, it is used to enhance the conceive (C) and design (D) phases of the SP-CDIO Framework as shown in Figure 2.

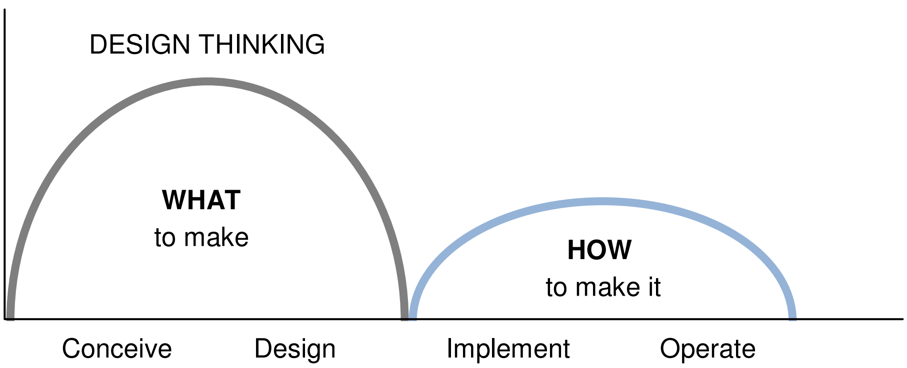
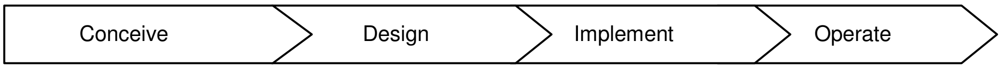


Figure 2: Incorporating Design Thinking into the C & D stages

The integration of design thinking into chemical product design in the 3-year chemical engineering curriculum is shown schematically in Figure 3.



Year 1	Year 2	Year 3
Introduction to Chemical Product Design (ICPD)	*Product Design and Development (PDD)*	*Final Year Project (FYP)*
User empathy	Technical Feasibility; Business Viability	

Figure 3: Integration of Design Thinking into Chemical Product Design

In Year 1, we have a new module *Introduction to Chemical Product Design* (*ICPD*), where students learn DT principles, with emphasis on its application in chemical product design. *ICPD* was first introduced in Semester 2 of AY2011 and is offered to all Year 1 students in every Semester 2 of future AYs. Reason for *ICPD* introduction in Semester 2 instead of Semester 1 of every AY is to allow students to gain fundamental understanding of chemical engineering that are covered in a module *Introduction to Chemical Engineering* (*ICHE*) in Semester 1.

In *ICPD*, we cover topics such as user empathy where students will conduct user needs understanding through ethnographic observations and interviews. The key at this juncture is for students to uncover latent or unarticulated needs, which are often neglected and unmet. More often than not, these unmet latent needs are the pinch points to a better process, system or production solution.

After the data gathering phase, students will be put through an ideation process where they need to generate as many ideas as possible using a series of ideation techniques. They will then rank and select their top ideas using defined criteria. Finally, students will be required to create a concept (“quick-and-dirty”) prototype to demonstrate their top ideas.

An outline of the syllabus for the *ICPD* module is shown in Appendix 1. From the onset, consistent with CDIO Standard 8 *Active Learning*, we have designed the module to be very hands-on in nature, to expose students to design-implement experience at an early stage, and to pique their interest in studying chemical engineering, even before they will learn the principles in details in their later years of study. The activities in ICPD include the following:

- The Art and Science in Coffee Making
- Vacuum Cleaning Power
- Concoct a New Detergent
- Design a Perfect Chewy Gummies

The four activities can be broadly divided into reverse engineering (RE) and chemical engineering sciences (CES) activities. The RE activities, namely *The Art and Science in Coffee Making*, and *Vacuum Cleaning Power*, involve students dissembling and reassembling commercial household products such as drip coffee maker and vacuum cleaner. Through the RE activities, students will be made aware of how chemical engineering principles such as heat transfer, filtration and pressure losses are being applied in daily products.

On the other hand, the CES activities, namely Concoct a New Detergent, and Design a Perfect Chewy Gummies, aim to introduce how sciences such as chemistry, physics and biology are being applied in the design and formulation of daily products like detergent and food gummies. Furthermore, we have also included concept of sustainability, the need for sustainable development, and global mindset throughout the four activities.

We also made changes to the original *PDD* module so that students can build on the prototype they produced in Year 1. They will also apply the chemical engineering principles learnt in other core modules in Year 2 to ascertain the technical feasibility of their design. If the work proves feasible, they can then carry on the product design and development work as their *Final Year Project (FYP)* in Year 3, whereby they will execute the “Implement” and “Operate” stage of their product design and development; as well as well as assessing the business viability of the product. The revised *PDD* module also includes new topics such as product lifecycle analysis (PLA) and systems thinking so that students can better understand the impact of the product design that they conceived on the environment and society.

CHALLENGES FACED AND APPROACHES TAKEN TO OVERCOME THEM

One of the major challenges faced by the authors is that both of us are trained in “traditional” chemical engineering that did not include chemical product design. Both of us received our chemical engineering training that focused exclusively on process plant design. We also did not have the relevant working experience in this area. Similarly, DT is a new concept for us.

We tackled the challenge of our lack of product design knowledge by riding on the SP-wide initiative to introduce the teaching of DT, via several pilot-scale multi-disciplinary projects (MDPs) carried out in AY2010 and AY2011. These projects involved students from different diplomas with diverse background and interests, working on “wicked problems” [10] that has innumerable causes, is tough to describe, and doesn’t have a right answer. Table 1 showed the various projects undertaken by the authors in their journey to build capability in this area.

Table 1: Building Capability in DT by the Authors

Mar – Apr 2010: (6 continuous weeks, during AY2009 Semester 2 vacation)	MDP: Experience at Outpatient Clinic in Local Hospital (First author) Community Engagement with Local Hospital (Second author)
Since 2010: Ongoing studio projects and workshops with companies such as Boeing, Procter & Gamble, Hill Rom and Kraft	MDP: Live Well Collaborative Singapore (First author) - see Note 1
Oct 2010 – Feb 2011: (3 hours per week for 15 weeks, as part of AY2010 Semester 2 timetable)	MDP: “The Fun Theory” (Second author)
Note 1: Based in SP, LWCS is an extension of the Live Well Collaborative in Cincinnati (LWCC), the breakthrough business-academia partnership model pioneered by Procter & Gamble and the University of Cincinnati in the US.	

To prepare for these projects, SP management brought in experts from the field, notably Vijay Kumar from Illinois Institute of Technology and Roger Martin from Rotman D-School. In addition, the first author also went on a two-week DT training in Cincinnati and New York in 2010. After the initial trainings, we were paired up with more experienced faculty in managing our respective projects. As can be seen from Table 1, these projects are not our typical engineering projects. With such initial “buddy” system, we built up confidence in our ability to handle them, and along the way, developed our DT competency.

With the knowledge and skills gained, we first piloted the teaching of DT in Semester 2 AY2010 with a 30-hr Year-1 module which was slated to be phased out by AY2011. Feedback and discussions with students during this pilot run showed that they are receptive to the use DT. Many expressed awareness of application of chemical engineering principles in product design, as opposed to the "traditional" process design. Some students however, did express some initial "discomfort" in the "new" way of teaching (working in small groups, and making numerous presentations). Nevertheless, they were able to come up with some interesting ideas such as toilet cleaning "grenade", automated sugar cane juicer, dustless fan and biofuel stove.

Some challenges faced by students in the pilot run include:

(1) Discomfort with "soft" approaches of divergent thinking that is inherent in DT. Students typically started off showing preference for more logical and analytical thinking of "hard" engineering.

(2) Related to the above – students faced uncertainty in adopting a conceived solution, as it may lack the absoluteness of an engineering calculation.

(3) Students generally lacked confidence in applying yet-to-learn chemical engineering principles.

(4) Students were unwilling to adopt some possible solutions, albeit innovative and interesting, because the solutions are deemed more "mechanical" or "electrical" in nature; or otherwise did not lend itself to application of chemical engineering principles.

These factors were taken into considerations in the subsequent design of the *ICPD* module. As mentioned earlier, *ICPD* was introduced for the first time in Semester 2 of AY2011. In total, six classes of Year 1 students (around 120 students) took the module where each class was taught and facilitated by a different faculty. The next section focuses on our initial experience with the module.

KEY LEARNING POINTS

In our opinion, two key leaning points stand out that merits careful consideration. One is the mindset of faculty teaching DT-infused modules, and another is the need for good facilitation skills. The teaching faculty must first adopt a new mindset and be receptive to the new teaching pedagogy that in turn, requires them to first overwrite their "traditional" approach to handling chemical engineering modules. In other words, the teaching faculty must take care not to fall back into the "usual" way of problem solving, especially given the time pressure to complete the curriculum within the prescribed period, i.e. one semester.

Hence, despite the trainings that we had, teaching DT at the initial stage proved challenging for us, as it ran counter to the way we were trained as engineers – to be analytical and somewhat procedural in applying an engineering solution. We found conducting debriefed or sharing sessions among the teaching faculties to be very useful, as they enabled us to share experiences and plan better for the next lesson.

In addition, there is a strong need for faculty teaching DT classes to possess excellent facilitation skills. This is one skill set that we, trained under the "old school" chemical engineering, did not possess. However, we were fortunate to have benefitted from our earlier MDP experiences; whereby we were able to learn on-the-job from experienced DT trainers. Despite that, we still had to constantly remind ourselves of our new role in classroom, moving from "sage on the stage" to that of "guide by the side".

Besides the urge to prescribe a given solution, we must also restrain ourselves from imposing our ideas on the students. Should they really go off-course, we need to tactfully steer them back without being seen as dictating what or how to solve the problem. As such, building rapport with the students at an early stage is crucial. Facilitation is thus especially important during the initial stages, where students tend to spend more time than allocated on a given task (e.g. interview, brainstorming or ideation). Also, facilitation is often very situational, which means that we must constantly be on the alert and detect any sign of uneasiness among students.

Another important point is the readiness with which we as faculty, need to admit that at times, we do not have all the answers. To this end, we felt that besides "good people skills", another important requirement for good facilitation is that a faculty must read widely and be knowledgeable in many diverse fields, though not necessary as an expert. It is the breadth of knowledge that matters more than the depth.

Lastly, the introduction of RE and CES activities that are also not typical of "traditional" chemical engineering experiments required teaching faculty to make a concerted effort to rationalise to students the importance and relevance of such activities to chemical engineering. It is again the use of good facilitation that can help students see the learning behind all the activities.

MOVING AHEAD AND CONCLUSION

Some ideas to move forward in this new exciting field of chemical engineering include: (1) develop case studies based on past FYPs to better motivate students; by creating the "I can do it too!" attitude; (2) introduce more hands-on sessions in the Year 2 PDD module, to allow students to refine their prototypes from ICPD; (3) revise the student-initiated project proposal process to encourage students to carry forward their prototype from PDD to FYP; and (4) make revisions to project FYP assessment scheme to include user empathy and ideation.

We also need more colleagues to come on board the DT bandwagon. The greatest obstacle to this is perhaps the need to change mind set of some faculty, who remain unconvinced of DT. Many faculty are also not comfortable with using techniques such as brainstorming where one cannot retain "control", and are especially uneasy with the uncertain outcome of DT projects. Some may also be worried that they may lose their credentials if they admitted to their lacking of knowledge in certain areas, even though these may lie beyond their domain knowledge. Many briefing and training will have to be conducted in order to achieve the desired positive mind set change.

While the "verdict" is still pending, we looked forward to better quality *FYP*s, with students being able to incorporate more factors into considerations during all the four stages of executing their projects, from conceiving, designing, implementing and down to operating a chemical process or product. Lastly, the old adage "practice make perfect" certainly holds true, and both authors are continually refining their skills by taking on more teaching of such DT-infused modules.

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Biographical Information

Claire Huiting Ng is a lecturer in the Diploma in Chemical Engineering (DCHE). She is also currently a Year 2 coordinator in DCHE Course Management Team, an Academic Mentor for School of Chemical & Life Sciences, as well as a facilitator working on projects with companies like Boeing, Procter & Gamble and Hill Rom in Live Well Collaborative Singapore (LWCS). She has a keen interest in education pedagogy and is currently one of the few faculties with experience in design thinking. Besides education pedagogy, she also has a strong interest in water-related projects. She currently has an Innovation Fund research project on using reflux-recycle concept for seawater desalination, as well as a consultancy project on producing water for disaster relief.

Sin-Moh Cheah is a chemical engineer turned academic. He is the Deputy Director in Singapore Polytechnic, overseeing various applied sciences diploma, including the Diploma in Chemical Engineering. He has lectured on various topics including chemical engineering principles, separation processes, and chemical reaction engineering. His current portfolios include curriculum revamp, academic coaching and mentoring, and using ICT in education. His current scholarly interests are learning pedagogy, curriculum re-design and program evaluation.

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Appendix 1: Brief Information about *Introduction to Chemical Product Design*

Module Synopsis

This module will develop students with an aptitude for chemical product design. The experiential learning module is infused with Design Thinking. It covers ethnographic observation tools and interviews to identify customer needs, as well as ideation techniques and ideas selection methods to fulfil preliminary product design specifications. Students will also create 3D "quick and dirty" prototypes and design portfolios. In addition, the module is encompassed with key CDIO skills and attributes such as teamwork, communication and creative thinking.

Module Aims

At the end of this module, students will be able to:

1. Identify customer needs using ethnographic observation tools and interviews.
2. Translate the identified customer needs into preliminary product design specifications.
3. Apply a range of ideation techniques and ideas selection methods to fulfil the preliminary product design specifications.
4. Create 3D "quick and dirty" prototypes of the selected ideas, as well as a design portfolio.
5. Work and communicate effectively in design teams.

Module Syllabus in Topical Form (specific learning outcomes not included)

A	INTRODUCTION TO CHEMICAL PRODUCT DESIGN AND DESIGN THINKING	
	Understand Chemical Product Design and Design Thinking	2 hrs
	Understand Chemical Engineering Principles in Chemical Product Design	10 hrs
	Apply Design Team, Teamwork and Communication	6 hrs
	Understand Design Portfolio	4 hrs
B	IDENTIFY CUSTOMER NEEDS	
	Apply Customer Needs Analyses	10 hrs
	Understand Preliminary Product Design Specifications	8 hrs
C	IDEATION, SELECTION AND PROTOTYPING	
	Apply Ideation Techniques and Ideas Selection Methods	14 hrs
	Apply "Quick and Dirty" Prototyping	6 hrs
	TOTAL	60 hrs