# DESIGNING LEARNING EXPERIENCES FOR TEACHING & ASSESSING THE CDIO SKILL HYPOTHESIS TESTING

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## ABSTRACT

The Diploma in Chemical Engineering (DCHE) in Singapore Polytechnic adopted CDIO as the organizing education framework for a major curriculum redesign initiative in 2007. Subsequently, various CDIO skills have been incorporated in specific core modules in the diploma's three-year curriculum. This paper explains one such integration effort, specifically for hypothesis testing, a key CDIO skill in Section 2.2: Experimentation, Investigation and Knowledge Discovery. From our gap analysis, we find that this skill is most suitably embedded into the bio-processing related modules.

To provide a good understanding of the context of this work, this paper firstly outlines the expanded role of chemical engineers in the area of bio-processing and how the course structure and curriculum has been revised to align with these needs. We emphasize the significance of student competence in being able to formulate, state and test hypothesis in bio-processing work. We explain the need to provide authentic learning experiences to students to facilitate the learning of both the technical subject and soft skills in a fully integrated manner. Specifically the paper documents the work done to integrate hypothesis testing into a Year 2 core module entitled *Bioanalytics*. Other CDIO skills (e.g. teamwork, communication) are also integrated where appropriate.

We explained important learning points from previous practices in the module, which clearly communicated to us that we need to do more if we want our students to master this important skill. This paper also describe the re-designing of learning tasks based on real-world scenarios that provide for an authentic learning experience and aligns with the intended learning outcomes. We then present the survey of our students' learning experience in this new approach. The results are highly encouraging as they show that the students feel they are well prepared with regards to hypothesis writing and testing.

In conclusion, several challenges faced when executing the change initiative and key learning points from the first author's self-reflection, who is relatively new to the teaching profession, are shared together with ideas for further improvement of the coverage of "Experimentation, Investigation and Knowledge Discovery" in the DCHE curriculum.

(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** – Bioprocessing, hypothesis testing, curriculum integration

## INTRODUCTION

The Diploma in Chemical Engineering (DCHE) in Singapore Polytechnic adopted CDIO as the organizing education framework for a major curriculum redesign initiative in 2007. Subsequently, various CDIO skills such as teamwork and communication, personal skills and attitudes (e.g. critical and creative thinking, managing learning, holding multiple perspectives) have been integrated into the curriculum [1, 2]. Also, skills relating to conceiving, designing, implementing and operating a process, product or system using relevant principles had been incorporated in specific core modules in the diploma's three-year curriculum.

This paper covers a new application by the DCHE Course Management Team (CMT) to introduce a new CDIO skill, namely Experimentation and Knowledge Discovery, into the chemical engineering curriculum.

## INCORPORATION OF BIOLOGICAL SCIENCES IN CHEMICAL ENGINEERING

This section provides the background on why Experimentation, Investigation and Knowledge Discovery and hypothesis testing in particular, is relevant to the students of chemical engineering.

In June 2000 the Government of Singapore, led by the Economic Development Board, launched a new initiative to make the country one of the global hubs for biomedical sciences (BMS). The BMS sector is to become the "next pillar of growth" for the country, and covers pharmaceuticals, biotechnology, medical technology and healthcare services. Since then various world-renowned companies and research institutes have set up both research centres and manufacturing bases in Singapore. In 2002 a workshop was held in the U.S to discuss the directions of the chemical engineering discipline with participation from industry and academia. A key conclusion of the workshop was that chemistry and biology are reaching equal standing as foundational sciences upon which the current discipline of chemical engineering is built; and that all chemical engineering majors should receive a minimum level of exposure to biological and cellular reactions and processes [3].

Then in 2003, under the auspices of the Council for Chemical Research (CCR) and with financial support from National Science Foundation (NSF), the Massachusetts Institute of Technology (MIT) organized a series of workshops (under the theme of Frontiers in Chemical Engineering Education) to examine initiatives to improve the existing chemical engineering curriculum. One of the outcomes of these workshops is the recognition that the chemical engineering curriculum needs to "demonstrate that graduates have a thorough grounding in the basic sciences including chemistry, physics, and biology appropriate to the objectives of the program; and sufficient knowledge in the application of these basic sciences to enable graduates to design, analyze, and control physical, chemical, and biological processes consistent with the program education objectives." [4].

Responding to the above-mentioned changes, universities around the world revamped their curriculum and offered bio-related programs [5, 6, 7]. For our part, we also took measures to align our curriculum by first integrating relevant bioprocessing applications into suitable core modules covering "traditional" chemical engineering including reactor design, heat exchanger design, separation processes. We then worked on rationalizing the course structure and to introduce new modules covering bioprocess-specific requirements.

From Academic Year 2005 onwards, we progressively rolled out three modules dedicated to bioprocessing, across the 3-year of study:

Year 1: *Pharmaceutical Microbiology*

Year 2: *Bioanalytics*

Year 3: *Bioprocess Engineering Principles*

These are supplemented by a number of elective modules in Year 3, such as *Biopharmaceutical Manufacturing* and *current Good Manufacturing Practices*.

## IMPORTANCE OF HYPOTHESIS TESTING IN BIOPROCESS ENGINEERING

Hypothesis testing is one of the important skills that students who study bioprocessing need to master. In bioprocessing, the number of variables that are of interest to the chemical (or in this case, the biochemical) engineer are more numerous than that in "traditional" chemical processing. Characteristics of bioprocessing data include: material input (quantity, quality control records, lot number, etc), process output (cell density, product concentration, quality, etc), control actions (base addition, carbon dioxide, oxygen flow rate, etc) as well as physical parameters (agitation rates, temperature, etc) from the frozen cell vial to the production scale bioreactors [8]. Mining bioprocessing data is therefore an important step in knowledge discovery. However, the data acquired typically includes some parameters that are not readily amenable for analysis. Hypothesis testing therefore becomes a key component of this process.

However, many engineers typically have difficulty understanding concepts like null hypothesis, confidence interval and similar concepts in statistical studies [9]. Most textbook examples frequently frame hypothesis testing within a series of mechanical steps requiring students to identify the hypotheses, graph regions of rejection, calculate test statistics, developed critical values, and then render a decision [10]. This often leads to poor understanding of the reasoning behind the structure of hypothesis testing even if they can procedurally do all the textbook exercises [11].

Shuler [12] emphasized the importance when he noted: "… biologists are particularly sensitive to the use of appropriate experimental controls; a concept not stressed in traditional engineering education where experiments are usually evaluated by comparison to theoretical expectations." There is thus a need to develop a pedagogical approach in teaching the subject to help students enhance their inferential reasoning skills.

The adoption of CDIO is timely in that it provided a structured methodology that we were seeking to integrate hypothesis testing into our curriculum. We adapted and customized the original MIT CDIO Syllabus (based on the original version 1.0) and developed SP's own CDIO syllabus. A comparison between the two syllabi for Section 2.2 Experimentation and Knowledge Discovery is shown in Table 1.

Table 1
Comparison between MIT and SP CDIO syllabus for Section 2.2
Experimentation, Investigation and Knowledge Discovery

| MIT CDIO Syllabus | | SP CDIO Syllabus | |
|---|---|---|---|
| 2.2.1 | Hypothesis Formulation<br>• Critical questions to be examined<br>• Hypotheses to be tested<br>• Controls and control groups | 2.2.1 | Formulate Hypothesis<br>• Select critical questions to be examined<br>• State hypotheses to be tested |
| 2.2.2 | Survey of Print and Electronic Literature<br>• The literature research strategy<br>• Information search and identification using library tools (on-line catalogs,<br>• databases, search engines)<br>• Sorting and classifying the primary information<br>• The quality and reliability of information<br>• The essentials and innovations contained in the information<br>• Research questions that are unanswered<br>• Citations to references | 2.2.2 | Conduct Literature Review<br>• Conduct information search and identification using library tools (online catalogs, data bases, search engines)<br>• Sort and classify information<br>• Evaluate the validity and reliability of information<br>• Cite relevant sources of information |
| 2.2.3 | Experimental Inquiry<br>• The experimental concept and strategy<br>• The precautions when humans are used in experiments<br>• Experiment construction<br>• Test protocols and experimental procedures<br>• Experimental measurements<br>• Experimental data<br>• Experimental data vs. available models | 2.2.3 | Conduct Experimental Inquiry<br>• Construct Experimental Design<br>• Conduct Experiment |
| 2.2.4 | Hypothesis Test, and Defense<br>• The statistical validity of data<br>• The limitations of data employed<br>• Conclusions, supported by data, needs and values<br>• Possible improvements in knowledge discovery process | 2.2.4 | Analyze Data and Write Report<br>• Analyze Data<br>• Write Report<br>• Appraise possible improvements in knowledge discovery process |

Also, consistent with the overall direction in the development of the SP-CDIO syllabus, we developed underpinning knowledge [13] for this section. A sample underpinning knowledge for “Formulate Hypothesis” is shown in Table 2.

The plan is to introduce this important skill into the 3-year curriculum in a manner that is consistent with our past integration efforts [2], as shown in Figure 1.

Table 2
Sample Underpinning Knowledge for Formulate Hypothesis

***Select critical questions to be examined***

- According to the subject of study, questions can often be differentiated into three general types: (A) Conceptual: where an attempt is made to explain an observed phenomena; (B) Practical: where an attempt is made to solve an existing problem; (C) Applied: where an attempt is made to achieve a deeper understanding of the subject of study.
- Whether a question is critical can be gauged by the following criteria: (A) does it expand the current body of knowledge; (B) is it relevant to the needs and pursuits of the community at large or to that of a specific industrial and research field; (C) does it draw from the accumulated knowledge of the relevant field or problem in its formulation.
- Questions that are asked may lead to ‘primary’ or ‘secondary’ research. Primary research is the discovery of knowledge via the initiation of studies on the researcher’s part (e.g. experimentation, performing surveys) while secondary research generates new knowledge from existing data or studies by further explorations such as data analyses and trending exercises.
- Questions should be concise and clear, and framed in a way that can conceivably be answered.

***State hypotheses to be tested***

- A hypothesis is a proposed tentative answer or solution to the questions posed. A good hypothesis should be: (A) a statement that is specific and clear in its proposition; (B) be testable or falsifiable by either performing experiments or making pertinent observations; (C) predictive of the anticipated results.
- A hypothesis can be stated in a “IF-THEN” fashion whereby it proposes a relationship between two variables in the subject of study and makes predictions of how the variation of one variable (independent or manipulated variable) would affect the other variable (dependent or responding). The relationship may be a cause-and-effect relationship or may be a simple correlation.

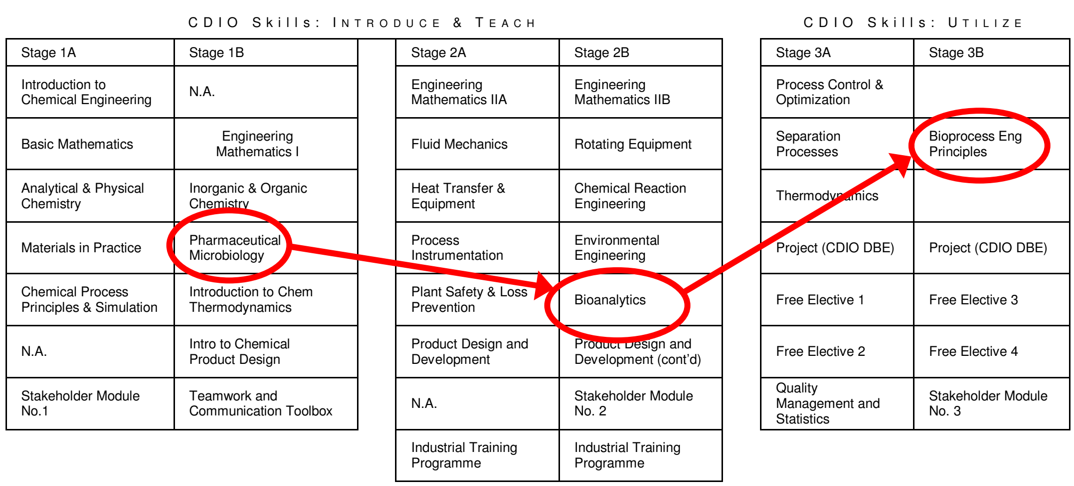


Figure 1. Integrating Experimentation & Knowledge Discovery skill across a three-year DCHE curriculum

## INCORPORATING HYPOTHESIS FORMULATION AND TESTING INTO A BIOPROCESS ENGINEERING MODULE

### Existing Practice

Our initial attempt at incorporating hypothesis testing into the DCHE course curriculum was through one of the laboratory activities for *Bioanalytics*. During this initial attempt, the topic was not explicitly covered during lectures. Instead the lecture content focused more on technical aspects of the subject as it is a new area for students. The faculty then made use of time during laboratory lessons to brief students about hypothesis formulation and testing. The students were then tasked to formulate a hypothesis which is to be tested in the subsequent laboratory lesson. During the two weeks preparation time which follows the laboratory briefing, the faculty adopted a somewhat “guided” approach and facilitated “consultation sessions” whereby students were encouraged to discuss with the faculty their formulated hypothesis and their approach to test it.

To facilitate the faculty in gaining some insight into the learning experience of the students who learned via the existing practice, a survey deploying a 5-point Likert scale was conducted on one cohort of 63 students. 56 students of the cohort responded to the survey invitation, corresponding to a response rate of 89%. Among the findings from this survey, the response to one particular question were of tremendous value to the faculty’s evaluation of the existing method.

62% of the cohort surveyed agreed that they would benefit more if a separation session was allocated to give them more practice in hypothesis formulation. In one of the feedback received, the student expressed that the “preparation part” of the learning activity was his least favorite part of the entire learning experience, a likely indication of the “frustration” that the student faced when formulating a hypothesis to be tested.

The potential benefits of having a dedicated session to teach hypothesis formulation was impressed upon the faculty through interactions with his students during the “consultation sessions”. The faculty observed that the initial hypothesis drafted by the students were often poorly drafted and lacked the desired qualities as stated in the underpinning knowledge for this CDIO skill as shown in Table 2. Even though the quality of the formulated hypothesis could be improved through formative feedback provided during the “consultation sessions”, the faculty felt that such an approach was not efficient in reaching out to students who did not opt to attend such sessions.

The above observations highlighted the limitations of the existing method and made it clear that more was to be done if we want our students to master this important skill.

### Re-designing the Teaching of Hypothesis Formulation and Testing

With this, we embarked on re-designing the entire teaching and assessment for this important CDIO skill. We used the student-centred approach of Felder and Brent [14] (as shown in Figure 2) to guide the activity re-design process, whereby the learning tasks and the assessment systems are now tightly aligned with the intended learning objective of helping the student to acquire the following CDIO skills, 2.2.1 Hypothesis Formulation and 2.2.3 Experimental Inquiry. The re-designed activity was subsequently adopted for the next cohort of DCHE students taking the module.

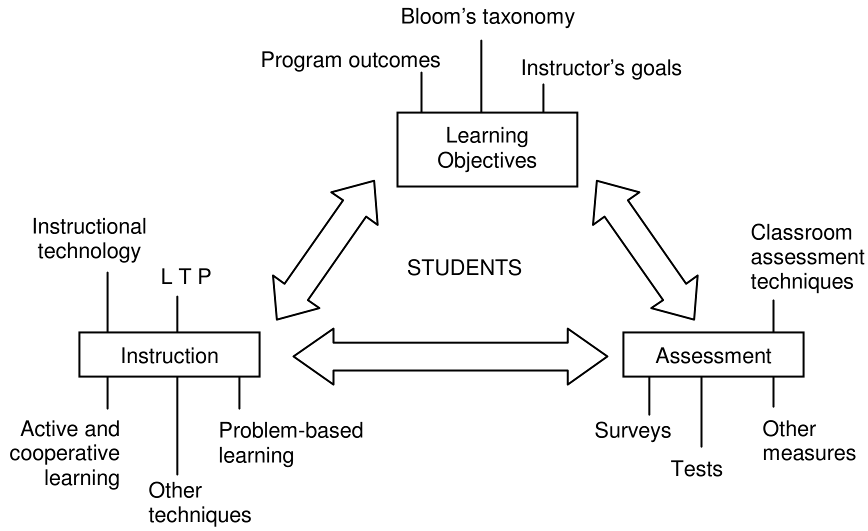


Figure 2. Student-centred approach to curriculum design

A lecture-based platform was chosen as the instruction method to help the student understand the specific requirements of hypothesis formulation and experimental inquiry. To minimize any learning inertia that the student may have for a new study topic, this lecture was packaged as a workshop to help them prepare for the hypothesis formulation and verification experiment which was an essential laboratory class assignment.

The content of the workshop can be summarized by as follows:

1. Introduction to hypothesis
2. Characteristics and structure of a properly constructed hypothesis
3. Experimental inquiry to test a hypothesis

To scaffold the learning process for students who are new to the concept of scientific hypothesis, straight forward everyday examples of formulated hypothesis were used during the lecture. The use of these examples was of value to this revamped activity as it helped to create resonance amongst the students. Next, a systematic approach was used to Illustrate to the students the characteristics and structure of a properly constructed hypothesis. This was followed by a guide to designing experiments for data collection and hypothesis validation. Finally, the key learning in the class was reinforced through a series of class activities that required students to utilize the knowledge taught during the workshop. Following the workshop, the faculty did not initiate the "consultation sessions" as per the previous practice but instead encourage the students to work independently using the knowledge acquired from the workshop.

**Use of Authentic Learning in Activity Re-design**

We also made modifications to the learning task in *Bioanalytics* to introduce authentic learning into the students' learning experience. The definition of authentic learning has been well discussed in the literature [15, 16] and can be interpreted as learning activities that gives the student a chance to be engaged in activities that mirrors how skills learned in the classroom are utilized in their future professions.

In an article discussing student's perception on authentic learning, Windham [17] discussed several benefits that students have derived based on conclusions from past authentic learning examples. In brief, authentic learning creates relevance for the students and helps them to make the connection between course content and their future careers. Through the skills acquired from authentic learning activities, students can become more confident and better prepared to enter the workforce. In authentic learning, students can also develop critical thinking skills through exposure to real-life, complex problems and get the chance to participate in teams that are multi-disciplinary in nature. Such benefits are taken into considerations in the re-design of the learning task of *Bioanalytics*.

We used simulated task scenarios to introduce authentic learning. In this case, students were posited as employees of a drug development and manufacturing company and the experiments are critical tasks in the production of a pharmaceutical product. The task scenario thus changes the nature of the laboratory activity from a purely academic exercise to one that is simulated to carry "real" consequences. To supplement the authenticity of the task scenario, the students were instructed to submit work memos and "official test certificates" to a "work supervisor" instead of a usual laboratory report.

**Results of the Re-designed Learning Task**

A separate 5-point Likert scale survey was conducted on the cohort of DCHE student who went through the re-designed teaching of hypothesis formulation and testing. The survey enabled the faculty to evaluate the benefits of this revamped learning activity.

The response rate for this survey was 81% out of 59 students. The key results from the responses collected can be summarized by the following statements:

1. 85% of the students who took part in the survey agreed that attending the workshop helped them to identify the characteristics of a well written hypothesis.
2. 75% of the students agreed that they now feel confident about hypothesis formulation and will be able to write a proper hypothesis for the laboratory activity
3. 83% of the students agreed that they are now proficient in applying the knowledge acquired in this workshop in other area of the course

The above results were highly encouraging as it showed that the revamped activity was able to improve students' awareness and confidence for this CDIO skill. More importantly, the faculty observed that the hypothesis submitted by students had significant improvements in quality as compared to the previous cohort. This observation was made based on the fact most of the hypothesis submitted satisfied the three important criteria as spelt out in the underpinning knowledge for hypothesis formulation (Table 2):

1. The hypothesis is a clear and non ambiguous statement
2. The hypothesis can be tested through experimental data
3. The hypothesis shows a clear relationship between the involved variables.

The above criteria were remarkably less evident in the hypothesis drafted by the earlier batch of students.

## CHALLENGES FACED AND KEY LEARNING POINTS

The faculty, who is the first author of this paper is a new member of the department and at the point of writing this paper, has approximately two years of experience as an academic. This section of the paper attempts to highlight some of the challenges and key learning that were experienced in the work leading to the revamped activities discussed.

The key challenges that the faculty faced during the progress of the work were as follows:

1. Establishing a sufficient proficiency and understanding of the CDIO education framework within a relatively narrow time frame.
2. Translating the newly acquired proficiency into module revamps that can improve the CDIO capabilities of DCHE students at an appropriate level.
3. Balancing the above task of Conceiving, Designing, Implementing and Operating of module revamp against the other responsibilities of an academic faculty.
4. Designing suitable tools to measure the effect of the CDIO revamps.

The CDIO framework is comprehensive and well-designed; thus requires a moderate learning curve, especially to someone who is new to pedagogical practices and teaching methods. In relation to this, the faculty found the respective CDIO resources such as the CDIO Standards and syllabus to be immensely useful in helping him develop a suitable level of understanding of the initiative. In particular, the faculty is grateful for the presence of a community of experienced CDIO practioners in Singapore Polytechnic, who helped him first in his action research project (mandatory for all members new to the teaching profession) and later coached him in the revamp of the Bioanalytics module [18]. This allows for the rapid build-up of the new faculty's CDIO capability. These experiences reinforces the importance of CDIO Standards 9 (Enhancement of Faculty CDIO Skills) and 10 (Enhancement of Faculty Teaching Skills) in an organization keen to CDIO implementation.

Such mentoring system had no doubt lessened the challenge faced by the new faculty in making the transition from industry to academia. Besides teaching, the faculty had to cope with various other administrative demands as a teaching professional while at the same time move quickly up the CDIO learning curve. Also, due to time constraints, the faculty opted for a simple survey questionnaire to gauge the students' learning experience on the re-designed learning tasks; instead of more elaborate instruments as used in past CDIO evaluations.

The faculty believes that Active Learning (CDIO Standard 8) is a critical component in the revamped learning activities that were described in this paper. In the revamped teaching of hypothesis formulation and testing, students had to utilize the knowledge gained during the workshop both during the in-class learning activities and also after-class when they had to formulate their own hypothesis for the laboratory activity. It is the faculty's opinion that students' internalization of the CDIO skill would be much less efficient if they were not given the opportunity to utilize the knowledge taught. The holistic experience that the new faculty acquired while doing the work described in this paper is arguably another form of active learning. Without the experience of designing, implementing and measuring the CDIO-related learning revamps that were described in this paper, the faculty believes very strongly that his understanding of the CDIO initiative would be very much reduced.

Although the *Bioanalytics* module that was described in this paper is a largely technical subject that focuses on disciplinary knowledge, the content in the results section of this paper demonstrated that students were able to acquire skills in hypothesis formulation and experimental inquiry, personal skills that are non technical in nature. These results highlighted the value of CDIO Standard 7 (Integrated Learning Experienced) in an engineering education programme.

As described by Crawley et al [19], the new faculty belonged to the current generation of engineers who received his engineering education that focused on the teaching of engineering science, rather than engineering practice. As such, the faculty noted some mismatch in the skill set that he had developed in school versus that required from a real-world engineer. From his own authentic experiences during his engineering education, the faculty concludes that much focus had been paid to disciplinary knowledge and that future engineering graduates could benefit greatly from the personal, interpersonal, and product and system building skills that are championed in the CDIO initiative. These additions to the engineering education pedagogy could help to narrow the gap that currently existed between the demands of the engineering industry and the renewed engineering graduate.

### CONCLUSIONS: IDEAS FOR FUTURE WORK

In this paper, the results and efforts taken by faculty in the Singapore Polytechnic DCHE course to improve student proficiency in the CDIO skill of Hypothesis Formulation and Experimental Inquiry were discussed. Through the incorporation of a lecture on the above CDIO skill into a re-designed laboratory activity, it was demonstrated that students' ability in formulating hypothesis and conducting experimental inquiry to verify hypothesis were improved. A survey of students who had gone through the revamped activity also reflected improved student appreciation regarding this CDIO skill.

As shown in Figure 1, students are expected to demonstrate competency in Experimentation and Knowledge Discovery when they move to their third year module *Bioprocess Engineering Principles*. As such, the faculty is currently working with another colleague who is teaching the *Bioprocess Engineering Principles* module, to align the expected learning outcomes at year 3 level. Also, the faculty recommended this CDIO skill be introduced to students right from year 1, via the *Pharmaceutical Microbiology* module. This recommendation is line with CDIO Standard 3 (Integrated Curriculum) and should be able to promote further improvements to student capability in this important skill set. Curriculum integration and learning experience of the students can then be enhanced by adopting novel pedagogies such as project-based and/or case-based learning.

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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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