HANDS-ON LEARNING: AN EXPERIENTIAL APPROACH TO TRAIN CHEMICAL ENGINEERING STUDENTS

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INTRODUCTION

Kolb[1] believes that knowledge results from the interaction between theory and experience. In their book *Teaching Science as Inquiry*, Carin and Bass suggest that "there are three major ways for people to learn about the world: discover things about the world from personal observations and experiences with the environment, acquire knowledge transmitted directly from other people or construct personal knowledge by transforming discovered and acquired knowledge in meaningful ways."[2] Recognizing that theory and experience go hand in hand, many institutes of higher education are shifting from traditional teaching paradigms and using student-centered learning (SCL) approaches to educate students.

The European Students' Union defines SCL as "both a mindset and a culture within a given higher education institution and is a learning approach which is broadly related to, and supported by, constructivist theories of learning. It is characterized by innovative methods of teaching which aim to promote learning in communication with teachers and other learners and which take students seriously as active participants in their own learning, fostering transferable skills such as problem-solving, critical thinking and reflective thinking."[3]

Recognizing that theory-centredness and experience-centredness are not conflicting but mutually reinforcing features of a learning environment, hands-on learning (HOL) as a student-centered model holds vast promise. While no one definition exists for HOL, our interpretation of HOL as an instructional model is largely influenced by Kolb's experiential learning theory (ELT) which suggests that "learning is a process whereby concepts are derived from and continuously modified by experiences."[1] In our Department, HOL depends on structured and unstructured laboratory sessions supported by lectures, reflection sessions, projects, and assessment. Laboratory sessions encompass a series of hand-on tasks which students perform as a team under the guidance of an instructor. Hands-on activities rely on real world problems and encourage students to construct their own knowledge "by doing and experiencing." In the efforts to solve the activity, the students gain an understanding of the foundational concepts and develop essential problem solving and critical thinking skills. Carrying out the tasks in teams allows students to build trust and confidence in one another and promotes free exchange of opinions and ideas. Timelines associated with the tasks teach learners to manage their time and efforts. With assessment focusing on learning and not on giving right answers, HOL encourages students to be creative and motivates them to produce professional quality work.

Several works appear in education literature that describe the benefits of using HOL or similar learning approaches to educate students.[4-8] Motivated to strengthen student-centered learning using the HOL approach, the Department of Chemical and Biomolecular Engineering at the National University of Singapore recently revamped the Year 1 curriculum. The initial discussions on a curriculum revamp within the Department highlighted the need to introduce a course that could offer the following:

Help Students Acquire Higher Order Skills. In graduate employment, engineering firms place high value on students' ability to be technically competent, think critically, solve problems, communicate effectively, work in teams, and exhibit ethical behavior. In a practical discipline like chemical engineering, a course that can assist students in acquiring twenty-first century skills from the start of their university life is thus vital.

Provide a Preview of Chemical Engineering. The annual Department graduate exit survey from 2016 suggests that students find Year 2 courses to be theoretically intensive and difficult to understand. This could possibly be attributed to the disconnect between the Year 1 and Year 2 curricula. In the words of a student, "*Year 1 courses did not introduce much to chemical engineering. Pursuing chemical engineering became tiresome in Year 2 and beyond…*" Noting this, it was imperative that the new course provide both a preview and bridge to the core courses, thus facilitating a seamless transition between the undergraduate years.

Make Students Aware of the Diverse Roles of a Chemical Engineer. While Singapore has long been an oil refining and chemical manufacturing center, in recent years it has emerged as a leading biomedical sciences hub and is the choice location for biopharmaceutical companies to develop and produce new products. A course that could provide the flavor of both the chemical and bioprocessing industries was needed to introduce the students to the diverse roles of a chemical engineer.

With the following objectives in mind, a two-part HOL-based course titled Chemical Engineering Principles and Practice (CEPP) was introduced in Year 1. Part 1 of the course (henceforth referred to as CEPP1) is offered in Semester 1 (Aug-Nov, 13 weeks) and serves to experientially introduce students to the foundational concepts of chemical engineering - namely fluid flow, heat transfer, mass transfer, reaction kinetics, etc. Part 2 of the course (henceforth referred to as CEPP2) is offered in Semester 2 (Jan-Apr, 13 weeks) and is designed to experientially introduce the basic concepts of biomolecular/biochemical/bioprocess engineering. Both CEPP1 and CEPP2 are conducted in a similar fashion. Since the inception of the course in August 2017, three and two runs have been conducted for CEPP1 and CEPP2, respectively. For the present paper, we focus on providing details of CEPP2, in particular course design, assessment, implementation, student feedback, and instructors' reflections.

COURSE DESIGN

Learning Outcomes

The process of designing the course began with translating the three broad course objectives into learning outcomes. It is expected that on successful completion of the course, students will be able to:

- Articulate the significance and relevance of the foundational principles of biochemical engineering and their link to the biotechnology/bioprocessing industry.
- Rationally design experiments, make observations, and critically analyze data to gain an understanding of the chemical engineering principles as applied to biomolecular manufacturing.
- Explain and demonstrate using bioprocessing technologies the ability to produce valuable chemicals and biomolecules.
- Communicate technical content in written and oral forms, with emphasis on organization, accuracy, truthfulness, and professional style.
- Work ethically and effectively in groups.

Course Syllabus

The syllabus was designed to provide students with foundational concepts of biomolecular/biochemical/bioprocess engineering with special focus on biosafety, upstream processing, and downstream processing. In parallel, it was expected that the chosen topics will give students a preview of the chemical engineering curriculum. Table 1 lists the syllabus topics and the core chemical engineering courses introduced alongside.

Course Structure. The pedagogical design of the HOL-based course is influenced by Kolb's ELC which states that the impetus for the development of new concepts is provided by new experiences.[1] Motivated by these thoughts, a four-stage learning approach was designed for CEPP2 (Table 2).

In line with the above, the students were taken through a 13-week journey comprising of lectures (two hrs/week), studio immersions (four hrs/week), workshops (three sessions/semester) and assessments. CEPP2 bore five modular credits and comprised a total of 11 lectures and 10 studio immersions.

Lecture. The weekly face-to-face lecture comprised of three components:

- Reflection session (30-35 min): During the reflection session, the instructors:
  - reviewed the studio activity completed in the past week and highlighted important experimental observations and conclusions;
  - shared queries most frequently raised by students;
  - discussed common misconceptions/mistakes made by students.
- In-class quiz (10-15 min): To facilitate and monitor the conceptual growth of the students, formative assessment in the form of a quiz was conducted. Each quiz, comprising of five multiple choice questions, was conducted with the help of the 'Poll Everywhere' application.
- Briefing on the upcoming week's studio (40-50 min): Students were provided with theoretical understanding of the concepts they were to explore through experimentation in the following week's studio.

Studios. Working in groups, weekly studio sessions allowed students to explore and learn concepts through experimentation, observation, and reflection. A total of 10 studio sessions (including two for the design project) were conducted over the 13-week semester (Table 3).

Pre-laboratory readings on theoretical background and laboratory procedures were provided to assist students in preparing for the studio. Studios required the students to design experiments, prepare samples, take measurements, and collect, analyze, and interpret data. At the end of each studio, student groups had to submit a short two-page report. The report needed the students to summarize their results, discuss their observations, and answer a set of open-ended questions. The open-ended questions were designed to promote self-reading and develop rational thinking among students.

An important component of the studio was the "chalk and talk" activity. As part of this activity, students had to present on a pre-assigned topic for five to seven minutes followed by four to five minutes of a Q&A session. Students were provided with a whiteboard and markers to assist them in their presentation. The presentations were recorded and made available to the students via the IVLE. (IVLE, short for Integrated Virtual Learning Environment, is a learning management system designed by the National University of Singapore to manage and support training and education over the Internet). Each student presented on two occasions during the semester. While the first presentation was ungraded, feedback was provided which helped the students to identify their weaknesses and strengths. The second presentation was graded.

TABLE 1
Course syllabus

Topics	**Core Chemical Engineering Course Introduced**	
	Course Code	Course Name
Biosafety	CN3135	Process Safety, Health and Environment
Bench scale cell culture	CN2101 CN2116	Material and Energy Balances Chemical Kinetics and Reactor Design
Bioreactor design and scale-up	CN2101 CN2116	Material and Energy Balances Chemical Kinetics and Reactor Design
Industrial enzymatic processing	CN2116 CN2122 CN3132	Chemical Kinetics and Reactor Design Fluid Mechanics Separation Processes
Protein purification and characterization	CN2116 CN3132	Chemical Kinetics and Reactor Design Separation Processes
Design project	CN4122	Process Synthesis and Simulation

TABLE 2
4-stage learning approach

Stage	**Focus**	**Routes**
Preparation	Acquire theoretical knowledge on topic/concept	Lecture, self-study, pre-studio group discussion
Experimentation	Gain practical exposure to facilitate enhanced understanding of topic/concept	Studio (laboratory) activity, laboratory report
Reflection	Develop in-depth understanding of topic/concept	Feedback on laboratory report, in-class reflection session
Application	Apply gained knowledge to solve problems	Design project, in-class quiz, term-end quiz

Design Project. Lasting over two sessions (eight hours), the design project challenged the students to produce a high quality alcohol product from fruits/vegetables of their choice using fermentation. Funds of SGD 10 (USD 7.25) were given to each team to purchase fruits/vegetables of their choice. The students had to carry out the project adhering to the following design constraints:

- Use of any fruits/vegetables or mixtures except grapes was permitted
- Fermentation was to be carried out in a standard 250 mL anaerobic vessel (reaction volume ≥ 50 mL)
- Addition of purified sugars or additives was prohibited, and only the provided yeast strain could be used

Students were informed of the assessment criteria (Table 4) prior to the start of the design project.

During the first design project session, sample preparation and fermenter set-up were performed by student groups. Fermentation was carried out under anaerobic conditions at 30°C. Three weeks later, during the second session, the students filtered the fermented sample to obtain the final product.

TABLE 3 **List of studio activities**	
Theme	**Objectives**
Safety and equipment training	• Understand general laboratory safety and waste disposal procedures; get acquainted to the location and operation of emergency equipment • Receive training on handling biological safety cabinet, centrifuge, autoclave, micropipette, microscope
Cell culture	Introduction to Sterile Techniques • Assess the viability of an unlabelled biological sample and explore the different sterilization methods to decontaminate the sample Cell Quantification • Learn cell density measurement using UV-Vis spectrometer • Prepare standard calibration curve
Cell growth kinetics	• Investigate different phases of batch cell growth and study how temperature and substrate concentration affect the growth of cells
Enzyme characterization	• Investigate the kinetics of enzymatic reactions using the Michaelis-Menten equation • Study the effect of inhibitor and temperature on suspended enzyme catalysis
Bioreactor design	• Design a bioreactor to obtain the target production yield
Large-scale biotransformation	• Design batch reactor experiment to obtain Michaelis-Menten parameters for immobilized enzymes • Compare between suspended and immobilized bioactivities
Product (protein) purification	• Explore the use of affinity chromatography to separate the protein of interest (enhanced green fluorescent protein) from a complex mixture (cell lysate)
Product (small molecule) purification	• Perform separation of two colored molecules using size exclusion chromatography and evaluate trade-offs between purity and yield at different operating flow rates
Design project	• Produce high quality alcohol product from fruits/vegetables using fermentation

The final product was characterized for:

- Quantity of sugars, alcohols, and acids by high performance liquid chromatography (HPLC*)
- Contamination from other microorganisms using microscope and agar plates
- Volatile compounds using gas chromatography-mass spectrometry (GC-MS*)

  (*HPLC and GC-MS were handled by laboratory staff)

The poster presentation was organized in the last week of the semester for students to share their design project outcomes. Two students from each team presented their work to the instructor for 10 minutes followed by 10 minutes of Q&A. All the members of the team were expected to participate in the Q&A session.

TABLE 4 **Design project assessment criteria**	
Criteria	**Weight (%)**
Ethanol titer	15
Residual sugar	15
Product smell	10
Choice of raw materials	20
Experiment design	20
Poster presentation	20

TABLE 5
Workshop details

Wk	Focus	Learning Objective	Student's Preparation	In-class Action
1	Workshop 1- Chalk and Talk	By the end of the workshop, students will be able to: • Convey information logically by: summarizing and synthesizing information, explaining the process of how a system/product works, and discussing applications based on guided principles/theories and evidence • Use diagrams/tables/drawings to present ideas on a whiteboard • Engage peers in the audience by asking/responding to questions and checking for understanding • Know the do's and don'ts of conducting a Chalk and Talk	None required	• Students share and discuss the best way to present ideas in small groups and then practice presenting their ideas to the class. Students must engage their audience by asking/responding to questions and checking for understanding • Other groups will provide feedback on clarity and supporting details used in the presentations
9	Workshop 2- Poster Presentation for Design Project	By the end of the workshop, students will be able to: • Identify the elements of a poster • Summarize key points for a poster • Design a poster • Cite sources using IEEE	• View materials on summarizing and paraphrasing • View IEEE reference guide documents • View materials on designing a poster	• Start literature search for the design project • Read the IEEE reference guide
12	Workshop 3- Oral Presentation	By the end of the workshop, students will be able to: • Present a poster • Use non-verbal techniques for effective delivery • Handle questions from the audience	• View oral presentation videos	• Prepare poster • Practice presenting the poster

Workshops. The workshops were conducted by the Centre for English Language Communication and focussed on students' development of oral and writing skills. The details of the three workshops are provided in Table 5.

ASSESSMENT

Assessments including quizzes, laboratory work, chalk and talk presentations, compilation and presentation of laboratory portfolio, and design project were used to measure the attainment of the learning outcomes. Table 6 shows the weights of the different assessment components.

Several practical considerations were made in finalizing the assessment methodology. Several studies have shown that end-point summative assessments such as final examinations do not encourage learning but rather force students to learn for the sake of obtaining grades alone.[9-10] It was decided that CEPP2 will be evaluated based on 100% continuous assessment with no end-of-semester examination. To ensure that students were assessed for their quality of learning and mastery of skills, a wide range of weighted assessments (to be conducted over the entire semester) were chosen to make up the final grade (see Table 6). The number of assessment components was carefully chosen to avoid over-or-underassessment. We expect the students to work independently and interdependently; a 50:50 ratio was thus chosen for individual to group assessments.

IMPLEMENTATION

A total of 254 and 214 students took CEPP2 in Semester 2 of academic year (AY)17/18 and AY18/19, respectively. Students were grouped in teams of five to six and assigned a team number. The allocation of members into teams was done on a random basis; the motivation was to train students to work with new people. A group of seven instructors facilitated lecture delivery and supervised the studios. Lecture notes and other reading materials were made available to the students via the IVLE. During the first lecture, the instructors briefed the students of the course objectives, learning outcomes, studio schedule, lab safety rules, and assessment methodology.

The studios were conducted Mondays to Thursdays (9 am-1 pm). On a given day, eleven teams carried out the laboratory activities under the supervision of three to four instructors. To instill leadership qualities, members of the teams took turns serving as the leader. The leader was expected to: conduct pre-studio meeting(s), direct the team members to accomplish the studio objectives, and chalk and talk on a pre-assigned topic. During the studios, the role of the instructors was to monitor student safety, train students in proper use of the equipment, ask questions to engage students' minds on a deep level, and grade chalk and talk presentations.

At the end of each studio, the students uploaded their reports onto the student submission folder in IVLE. To ensure consistency in grading, all the reports were graded by a single instructor. Every group received both verbal and written feedback on their report by the grader. As educators, we believe that giving feedback to every group personally, though time consuming, is essential for the success of HOL-based courses. Feedback guides students in their learning process, gives them direction, and allows for the creation of a harmonious and engaging learning environment.[11] Every Thursday evening, i.e. on the conclusion of the studio activities for that week, the instructors met to discuss their observations for the week. These observations were shared with the students during the reflection session of the forthcoming lecture.

STUDENT FEEDBACK AND REFLECTIONS

Student Feedback

To assess the achievement of the course learning outcomes, an in-class anonymous survey was conducted during the last

TABLE 6
Assessment components

Component	Assessment Type	Weight (%)	Assess Students' Ability To:
Quiz • In-class • Term-end	 Individual Individual	 10 20	• Understand biochemical engineering principles
Studio attendance	Individual	10	• Work effectively in groups • Rationally design experiments, make observations, and critically analyze data
Chalk and talk	Individual	10	• Communicate technical content verbally
Laboratory portfolio	Group	30	• Rationally design experiments, make observations, and critically analyze data • Communicate technical content in written form professionally • Work effectively in groups • Accomplish tasks on time
Design project	Group	20	• Use bioprocessing technologies to produce valuable end-products • Communicate technical content in written and verbal form professionally • Work effectively in groups • Accomplish tasks on time

TABLE 7
Student feedback

Question	AY	Strongly Agree (%)	Agree (%)	Disagree (%)	Strongly Disagree (%)
CEPP2 facilitated my understanding of the foundational principles of biochemical engineering and effectively demonstrated its link to the biotechnology/bioprocessing industry.	2017/18	31	61	6	2
	2018/19	36	60	3	1
Studio activities trained me well to design experiments as well as collect, analyze, and interpret data.	2017/18	26	65	7	2
	2018/19	34	61	5	0
Chalk and talk activities and feedback from instructors/peers helped me improve my oral communication skills.	2018/19	25	61	11	3
Compiling and presenting laboratory portfolio served to enhance my report writing skills, and I am better equipped to present technical content in a clear, accurate, comprehensive, and professional manner.	2017/18	16	74	8	2
	2018/19	26	68	6	0
Lab reports, chalk and talk, quizzes and design project collectively served to assess my learning in a holistic manner.	2017/18	21	66	9	4
	2018/19	27	59	11	3
Instructors provided adequate and timely guidance and ensured a positive and safe learning environment.	2017/18	45	45	5	5
	2018/19	50	47	3	0
Lectures and studio activities provided a good preview of the undergraduate curriculum and helped me understand how chemical engineering principles are applied to biomanufacturing.	2017/18	26	67	6	1
	2018/19	29	64	7	0
CEPP2 provided meaningful opportunities to critically engage in hands-on learning and inculcated well the spirit of independent and collaborative learning.	2017/18	30	63	4	3
	2018/19	35	62	2	1

lecture. Student responses are summarized in Table 7. A total of 252 (out of 254) and 210 (out of 214) students participated in the survey in AY17/18 and AY18/19, respectively.

Survey results suggest that the course learning outcomes were satisfactorily achieved with more than 85% of the students responding favorably to each of the questions. Students' perception on the difficulty of the course was discerned through NUS's student feedback report (Table 8). The number of respondents were 206/254 (AY17/18) and 105/214 (AY18/19).

Noting that CEPP2 is a level 1 course, it is satisfying to see that most of the students (≥88%) found the course difficult or averagely difficult. As instructors, it is important to bear in mind that too difficult a course could be frustrating for Year 1 students. On the other hand, an easy course does not challenge the students well and gives no sense of accomplishment to students.

For quality assurance, comments were collected from students for two questions:

Q1. What are the best aspects of CEPP2?

Q2. How can students' learning in CEPP2 be further enhanced?

Students' qualitative comments were thematically analyzed to obtain a deeper understanding of the feedback. As part of thematic analysis, students' comments for Q1 were evaluated first to generate suitable themes (Figure 1). Thereafter, students' comments under each theme were analyzed further to ascertain the laudable aspects of CEPP2 as perceived by students (Table 9).

The qualitative feedback concurs well with the quantitative feedback in suggesting that the course was well received by the students and that the course was able to deliver on many fronts. Students' qualitative feedback for Q2 was evaluated next. Figure 2 summarizes students' suggestions, and the analysis of students' suggestions is presented in Table 10.

As educators, we believe that the true virtue of a course lies in its ability to have a positive, long-lasting impact on the students. To understand if the knowledge and skills acquired from CEPP courses (CEPP1 and CEPP2) benefitted students in their later years of undergraduate education, a survey was conducted in August 2019. The survey was taken by current Year 3 chemical engineering undergraduates. They represent the first batch of students who were offered CEPP. Survey responses (No. of respondents: 135/254) are summarized in Table 11.

It is comforting to see that CEPP courses not only served to smoothen the learning curve for students as they progressed from Year 1 to higher years, but they also provided a preview of the chemical and biomanufacturing industries. We are hopeful that introducing students to the chemical and biomanufacturing industries from the start of their university life will assist them in making informed decisions when it comes to choosing elective courses, internship opportunities, or research projects in their senior years. To the qualitative question "Any additional training/topics that you feel should be part of CEPP syllabus", several students expressed the need to introduce MATLAB or other programming languages. Recognizing the importance of training students in computing, a new course titled Programming Methodology has been introduced for all first year students admitted into the Faculty of Engineering beginning AY19/20.

TABLE 8
Students' perception on the difficulty of the course

Question	AY	Very Difficult (%)	Difficult (%)	Averagely Difficult (%)	Easy (%)	Very Easy (%)
Rate the difficulty level of the course	2017/18	7	38	50	4	1
	2018/19	10	50	40	0	0

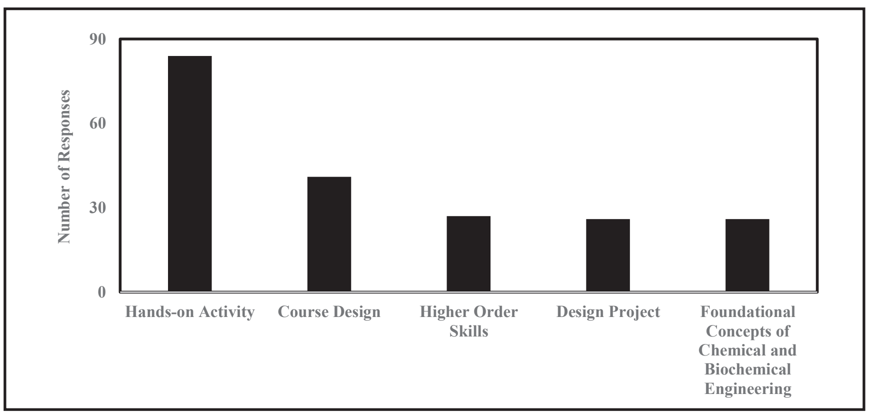

Figure 1: *Themes for Q1*

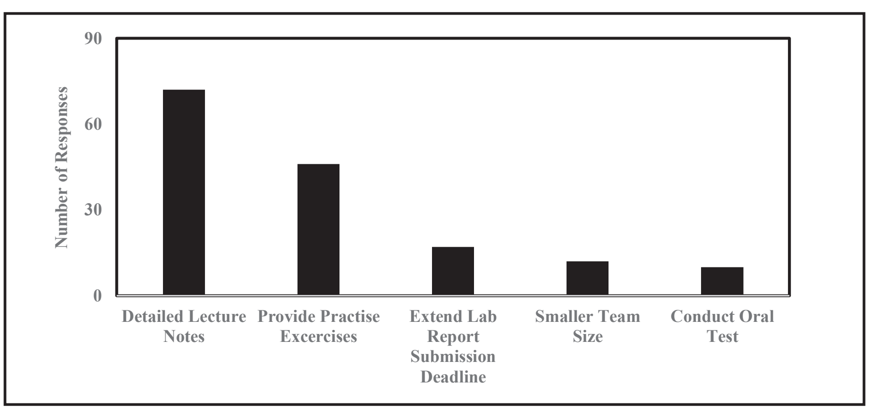

Figure 2: *Students' Suggestions*

Instructors' Observations and Reflections

In totality, the instructors were pleased with the learning gains made by students in their technical knowledge and soft skills. Below is the instructors' summary of students' performance for the various assessment components.

Studios. For the first two or three studios, most teams appeared unprepared, and members lacked coordination and struggled to finish the studio activity in a timely and professional manner. At this juncture, in-class reflection sessions played an important role in highlighting to teams their shortcomings and that coordination, effective communication, and adequate preparation in the form of self-reading and team discussions are keys to success for studio activities. As the weeks progressed, most teams started exhibiting better preparedness and coordination, students showed better understanding of the concepts, team leaders began taking charge, tasks got completed on time, and the quality of reports improved in terms of organization and technical content.

Chalk and Talk. Most students performed at an average level for their first chalk and talk. However, a significant

TABLE 9
Analysis of students' comments for Q1

Theme	Best Aspects of CEPP2
Hands-on-activity	Ample opportunities to learn by doing and observing; engaging and interactive experiments; provides avenue to learn new lab techniques/experimental skills; flexibility to design and conduct experiments
Course design	Learning aided through the use of real world scenarios; effective assessment; constant feedback supported learning; manageable workload
Higher order skills	Adequate training to improve communication, leadership, and time management skills and excel as an independent and interdependent learner
Design project	Fun and effective way to apply the concepts learned in CEPP2
Foundational concepts of chemical and biochemical engineering	Preview to chemical engineering curriculum; introduction to biomanufacturing industry

TABLE 10
Analysis of students' suggestions

Students' Suggestion	Instructors' Views on Students' Suggestion	Action Plan
Provide detailed lecture notes	By providing essential and not an overload of information in lecture notes, we can encourage students to review and read books/journal articles and motivate independent/peer learning	Provide reading references while retaining the current set of lecture notes
Provide practice exercises	Practice questions can help students to evaluate their own understanding of concepts	Practice questions in the form of ungraded self-evaluation tests will be made available
Extend lab report submission deadline	The current submission deadline of one day encourages students to compile the report while the experimental observations/data is still fresh in their minds	Current submission deadline will be maintained
Smaller team size	Decreasing the team size may significantly increase the workload of the students within a team. Increasing the total number of teams will also require additional resources/manpower/lab space	Current team size of five to six students will be retained
Conduct oral test	Oral test during each studio will motivate students to be well prepared for the studio	Oral test will be conducted at the start of each studio

improvement was noted for their second attempt. Students presented with more confidence and clarity, exhibited a deeper understanding of the topic, and handled the technical questions well for their second chalk and talk. We believe that feedback from instructors/peers, mutual learning from peers' presentations, and opportunity to review their presentation in IVLE and reflect contributed positively towards enhancing students' performance.

TABLE 11
Year 3 students' responses

Question	Strongly Agree (%)	Agree (%)	Disagree (%)	Strongly Disagree (%)
CEPP courses introduced me to the world of chemical engineering, thus giving me a technical head start to Year 2	10	65	21	4
Soft skills training received through CEPP courses enabled me to accomplish Year 2 projects/tasks in a more organized and professional manner	10	64	23	3
CEPP courses showed me that chemical engineers have an important role to play in chemical and biomanufacturing industries	22	64	11	3

Quizzes. Quizzes aimed to assess students' understanding of the theoretical foundation of biochemical engineering principles and the key observations during the studio activities. While the overall performance was satisfactory for the quizzes, a few students fared poorly for questions based on studio activities. This can possibly be due to insufficient pre-studio preparation, being overly dependent on their team leader/members for studio execution, and lack of attention to details of the experiment and its outcomes.

Design Project. All teams performed well for the design project. Not only did the teams conduct a thorough literature review to choose the right fruits for fermentation, the experimental protocols were prepared and executed adequately with little or no inputs from the instructors. The CEPP2 journey culminated with poster presentations with teams enthusiastically presenting the outcomes of their design project.

Proposed Changes in CEPP2. Based on student feedback and self-reflection, the CEPP2 team of instructors has decided to introduce four major changes in the forthcoming semester. The instructors feel that one of the areas that needs added attention is safety. While significant efforts were made by the Department to ensure a safe working environment - conducting safety briefing and a safety quiz (students had to score 90% or more in the quiz to be eligible to work in the laboratory), providing equipment training, and overseeing compulsory use of PPE during studio activities - one needs to realize that simply imposing rules can only garner limited success. To raise the safety bar further, it is important that we introduce more activities/trainings which can inculcate a safety mindset in students and help them develop a deeper appreciation for a safe work culture. Going forward, students will be required to submit a risk assessment to the instructors prior to conducting the studio activity. Only on satisfactory completion of the risk assessment for the studio will the students be allowed to perform the experiment. To familiarize students with the procedure of risk assessment, training will be conducted during the first lecture.

A common observation among instructors was lack of preparation by some students prior to attending the studio. To motivate students to be better prepared for the studio, an oral test will be conducted at the start of each studio activity. The oral test will be graded and will account for 5% towards the final scores of the student.

Thirdly, students will be provided with ungraded self-evaluation tests. Through the use of multiple-choice questions, the self-evaluation tests will provide students an opportunity to test their understanding of the topic.

Finally, a list of reading references for every studio will be provided to ensure that students refer to genuine literature for their preparation.

THOUGHTS FOR FELLOW EDUCATORS

For educators who wish to introduce a HOL-based course, here is our advice:

Preparation Time: In general, 8-12 months of time are needed to develop the course content (lecture, quizzes, studios) and conduct trial runs.

Resources: Instructor resources, equipment/consumables, emergency response kits and lab space needs are dictated by class size. For a large class size of around 200 students, five to six instructors, two laboratory staff, and ten to twelve laboratory set-ups of each experiment are needed. As each of the experiments involve sample preparation, taking measurements and analysing data, a team size of five to six students is adequate. This will ensure that each team member has an adequate but not overwhelming amount of work to do.

Course Design and Delivery: Learning objectives, instructional strategies, and assessment should be aligned. Designing the studios/laboratory activities around a central theme is important to enable students to see the larger picture. Students can benefit most from studio activities if they duly participate in pre- and post-studio activities. Pre-studio activities include attending lectures, doing self-study, and actively participating in group discussion. Post-studio activities include analysis of data, preparation of the laboratory report, and reflecting both independently and as a team. When conducting studios/lectures, it is important to showcase to students how different concepts/topics are related to Year 2/3/4 courses and their applicability in industry. Lastly, as advocated by Tan, "design a sequence of assessments to create a coherent series of assessment tasks over a period of time, instead of a one-off task, such that each assessment task works in relation with the rest and they feed into each other."[12]

Safety and Equipment Training: Adequate training in use of safety devices (including PPE) and laboratory equipment is required to facilitate no/minimal occurrence of incidents.

CONCLUSION

The student feedback has been encouraging, with many students finding the HOL-based course useful in facilitating their understanding of the principles of biochemical engineering; providing a broad overview of the chemical engineering curriculum; and offering meaningful learning opportunities to acquire a breadth of higher order skills. As educators, we need to realize that higher-order skills cannot be cultivated through passive education. Students need to be active learners and acquire knowledge through the process of listening, doing, observing, analyzing, presenting, and reflecting.

Wide acceptance of CEPP2 by students can be attributed to it being practical, relevant, and engaging. With a focus on learning through exploration and experience, CEPP2 gave students an avenue to be both creative and critical, independent as well as interdependent, and become better prepared for applied workplaces.

While it is gratifying to see CEPP2 being appreciated by students, the journey has just started, and concentrated efforts are needed to continuously reflect and improve the way CEPP2 and other chemical engineering courses are taught to the future generations.

REFERENCES

1. Kolb DA (1984) *Experiential Learning: Experience as the Source of Learning and Development*. Prentice-Hall. Englewood Cliffs, NJ.
2. Carin A and Bass JE (2000) *Teaching Science as Inquiry*. 9th ed. Prentice-Hall. NJ.
3. European Students' Union (2015) Overview in student-centered learning in higher education in Europe. http://esu-online.org/wp-content/uploads/2016/07/Overview-on-Student-Centred-Learning-in-Higher-Education-in-Europe.pdf accessed November 21, 2019.
4. Abdulwahed M and Nagy ZK (2009) Applying Kolb's experiential learning cycle for laboratory education. *J. Eng. Educ*. 98(3): 283-294.
5. Jaksic N (2010) Teaching PLCs using the Kolb learning cycle. *Proceedings ASEE Annual Conference*. https://peer.asee.org/16954 accessed March 2, 2020.
6. Abdulwahed M and Nagy ZK (2011) The Trilab, a novel ICT based triple access mode laboratory education model. *Comput. Educ*. 56(1): 262-274.
7. Konak A, Clark TK and Nasereddin M (2014) Using Kolb's experiential learning cycle to improve student learning in virtual computer laboratories. *Comput. Educ*. 72: 11-22.
8. Chen W, Shah U and Brechtelsbauer C (2016) The discovery laboratory - A student-centred experiential learning practical: Part I – Overview. *Educ. Chem. Eng*. 17: 44-53.
9. Sambell K, McDowell L and Brown S (1997) "But is it fair?": An exploratory study of student perceptions of the consequential validity of assessment. *Stud. Educ. Eval*. 23(4): 349-371.
10. Cilliers FJ, Schuwirth LW, Herman N, Adendorff HJ and van der Vleuten CP (2012) A model of the pre-assessment learning effects of summative assessment in medical education. *Adv. Health Sci. Educ*. 17(1): 39-53.
11. Race P (2004) Using feedback to help students to learn. *The Higher Education Academy* http://phil-race.co.uk/wp-content/uploads/Using_feedback.pdf accessed December 13, 2019.
12. Tan KHK (2013) Variation in teachers' conceptions of alternative assessment in Singapore primary schools. *Educ. Res. Policy Prac*. 12(1): 21-41. ❒