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Crafting Engineering Problems for Problem-Based Learning Curriculum

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Abstract

An effective problem is the heart of problem-based learning (PBL). It plays an important role in delivering the intended learning outcomes, assessing the learning process, providing learning context, stimulating thinking skills and catering for teaching and learning activities. Although a number of criteria that characterise effective PBL problems have been identified, crafting problems according to those criteria is a challenging task to problem crafters in most disciplines, especially engineering. The aim of this paper is to describe a guided technique, and yet easy to follow, for crafting PBL problems based on the experience implementing PBL at the Universiti Teknologi Malaysia (UTM). The criteria of effective PBL problem extracted from literatures are condensed into five main principles, deliberately constructed for crafting engineering problems. The five principles are aligned with the objectives of using problems for learning. A sample case study from Process Control and Dynamics, a chemical engineering course taken by the third-year undergraduate students, is presented to demonstrate the technique. The case study is mapped to the five principles of effective engineering problems. Feedback from students on the given case studies is also included to put forth their perspective about effective engineering problems.

Keywords: Problem Crafting; Problem-Based Learning; Higher-Order Thinking; Chemical Engineering

1. Introduction

Problem-Based Learning (PBL) is a student-centred teaching and learning methodology in which the problem comes first whereby the new knowledge is constructed on the foundation of prior knowledge. PBL lies in social constructivist learning framework as the learning environment is designed and executed to be inductive and cooperative [1, 2]. Unlike the conventional chalk-and-talk teaching approach, PBL enables the students to become producers, rather than consumers, of knowledge. Unstructured case studies that emulate real life problems or realistic ones develop students' cognitive and metacognitive skills, and also empower them to be self-directed and lifelong learners. As far as the content knowledge is concerned, PBL equips the students with the essential technical skills required for them while entering the actual workplace. Particular emphases are placed on critical thinking, problem solving and teamworking skills.

The idea of using problems as driving force for learning, particularly in PBL, have been discussed by Duffy and Cunningham [3], and Weiss [4], as follows:

- Deliver the intended learning outcomes
- Assess learning process and the achievement of learning outcomes
- Provide context of learning as well as professional practices
- Stimulate and train thinking skills
- Cater for teaching and learning activities

First and foremost, instead of giving lectures, the problem is used as an instrument to deliver the intended learning outcomes. However, students are by no means left on their own without being guided. In PBL, facilitation, scaffolding and motivation is crucial to support the learning process. Second, the problem functions as a test to assess the level of students' learning, either they reach only surface understanding or perform up to deep understanding. Third, the problem provides an explicit learning context to the students. The intended learning outcomes are embedded into the problem where application of certain concepts, principles or procedures are required in order to solve the problem. Besides, it portrays the job specification, illustrates the working scenario, and simulates the challenge that students may face in their professional practice. Hence, students are trained to suit themselves in the actual working environment. Fourth, problem serves as a tool to stimulate and train thinking skills, beyond than only to solve the problem. A problem that is designed at a certain degree of complexity is capable to promote higher-order thinking and enhance metacognitive skills. Fifth, the problem provides a basis for learning activities and activates the learning process to support the design and implementation of effective learning environment. The learning activities are meant to develop certain skills like self-directed learning, lifelong learning, problem-solving, critical thinking and communication.

In PBL, problems serve as the backbone of learning to cover the intended learning (or course) outcomes that includes acquisition of knowledge through deep learning and development of skills through participation in the learning activities. Educators should craft problems that motivate their students to learn and prepare the students for the real world by ensuring that the course outcomes are achieved once they solve the problems. As the problems act as stimulus for learning in PBL, crafting the problem itself is a challenging problem in most disciplines, including engineering. Engineering problems that fit a certain intended learning outcomes are hardly found in standard texts. On the other hand, typical end-of-chapter problems are too simple and not challenging enough to promote higher-order thinking, lifelong learning and teamworking skills. One way to deal with this issue is by crafting our own problems that cover the intended learning outcomes.

Unlike medical schools where learning takes place regularly in the actual work setting using real cases, working with doctors and dealing with patients, bringing "engineering world" into the classrooms is a painstaking process. In engineering disciplines, PBL problems must be customised to the industrial standards. The actual working environment cannot be easily modelled and simulated as simple as constructing mini courts in law schools. Besides, real engineering problems are highly technical for students to visualise, and also difficult for educators to transform them into written format. Nevertheless, crafting PBL problems for engineering curriculum still can be done by following the criteria of effective problem design.

An effective PBL problem can be a powerful trigger and motivation for students' learning process but it is not always easy to write one. Being able to craft good problem becomes critical skills for educators in PBL. While there is no formula for writing a good problem, there are some guiding principles in designing effective PBL problems where the intended learning outcomes can be infused inside them. This paper aims to describe the principles and the process of crafting effective engineering problems for PBL curriculum, based on the experience implementing Cooperative Problem-Based Learning (CPBL) in a chemical engineering course at the Universiti Teknologi Malaysia (UTM).

2. How to Craft Engineering Problems?

In general, problems can be classified into three different types: fictional, authentic and real [5]. However, real engineering problems are hard to find, and if any, they cannot be directly used for academic perspectives. Often modification and simplification is a necessity for real problems to be used for classroom benefits. Therefore, crafting the authentic ones is always a good alternative. In fact, an authentic-type problem is the most preferred version by PBL practitioners.

Crafting engineering problems for implementation in PBL curriculum is no doubt a challenging task. Apart from creativity, it requires a lot of effort that includes study of practical knowledge related to the course and also communication with the expert personnel from industries. The problems have to be industrial-based and not subject-driven. In other words, in the process of crafting engineering problems, problem crafters have to be constant learners themselves to be in touch with the challenges of society and industry.

2.1 Principles of Effective Engineering Problems

There are a number of criteria that characterise effective PBL problems have been identified and published in open literatures [4, 6, 7, 8, 9]. In this paper, the authors attempt to condense those criteria into five interrelated principles, align to the objectives of using problems in PBL, as shown schematically in Figure 1. Each of the principles is mapped to the corresponding supporting elements.

To provide explicit learning context to the students, the problem has to be authentic and realistic. It should represent the professional practice where the learning issues applied and the working environment that students will possibly encounter in the actual workplace. The problem should also require students to perform the same learning activities in the learning environment as they would in the actual working environment. The complexity of the problem should be suitable to ensure participation and engagement in cooperative learning climate, and thus promote self-directed learning and lifelong learning. While solving the problem, it should lead students to higher cognitive level where critical thinking and metacognition are applied.

Figure 1. Principles of effective PBL problems (Notes: O – objectives, P – principles)

2.1.1 P1: Authentic and realistic (if not real)

PBL is a powerful philosophy that empowers students to take charge of their learning agenda. To do so, students must be motivated to solve the problems, as soon as they first read them. Nothing impresses or motivates students more than to realise that the problems they are working with are authentic and realistic.

Thus, engineering problems designed for PBL curriculum should mimic those that students will likely encounter in their professional practice to prepare themselves for their professional career. It should be unstructured, represent the real work setting, relevant, and updated.

Real problem request neither calculation of something nor description of facts, but usually ask for concrete suggestions, justified decisions, technical reports, proposals, technical presentation, interview session, etc. Therefore, the intended learning outcomes should not be the end point of the problems, instead, being as the intermediates between problem and solution. In other words, the problem should reflect the demand at the workplace.

2.1.2 P2: Constructive and integrated

As PBL lies in constructivist learning framework [1], the problems must be constructive too. The intended learning outcomes should be embedded into the problem, connected to students' prior knowledge, and if possible, connected to the knowledge from other courses and/or disciplines. The problem should be designed such that students are unable to solve it by simply extending their current knowledge and skills. This extension requires for thorough activation of prior knowledge, deep understanding of new knowledge, and enhancement and/or development of certain skills.

In the actual work setting, people come from various educational backgrounds, and real work problems by nature cut across disciplines and blur the lines between courses of a discipline. However, engineering curricula that is separated into courses implicitly educate students to see the course outcomes as a cluster of neatly divided silos. They may understand the underpinning knowledge within each of the courses but may encounter difficulties in trying to generalise and integrate between them.

Although it seems complicated to integrate the learning outcomes from different courses, or even more difficult from different disciplines, infusing only certain learning outcomes from different courses into a problem still can be done, and it is very much encouraged. This is yet another approach to train the students to be real work ready. As far as integration of knowledge is concerned, designing engineering problems for PBL implementation in the first- or second-year courses need precaution as the student are in the process of learning the basic knowledge and the fact that their perspective towards professional practice is still vague.

2.1.3 P3: Suitable complexity

The size and complexity of the problem should be suitable that it requires cooperation a team of students to solve it. However, it should not be too simple that it can be conquered and solved by one person, or divided into small parts, solved independently and eventually assembled for submission. During the problem solving process, students have to function effectively in their respective teams to restate and identify the problem, exchange knowledge, argue against ideas, consider possible solutions, making decisions and synthesis appropriate solution. Besides, complexity of the problem should be designed such that students have to acquire problem solving skills to solve it.

If coverage of the learning outcomes of a particular problem is considerably big, then it is advisable to break up the problem into several parts and present them in sequence. Problems must be arranged in order of complexity and according to the phase of curriculum.

2.1.4 P4: Promote self-directed learning and lifelong learning

While the extension of the knowledge for a particular engineering discipline is very broad and always being updated, universities are expected to educate students with only principles and concepts of knowledge. On top of that, it is definitely impossible to bring everything into the classrooms and integrate in a four-year programme. The solution for this issue is by empowering the students to be self-directed and lifelong learners. However, students cannot be competent with such skills by themselves, instead, they need to be nurtured and trained continuously.

A problem that is authentic and provocative on its own is capable to create interest and motivate students to become self-directed and lifelong learners. For instance, when students solve an open-ended problem that is of real interest of them, they will probably find their own solution to be inadequate. Therefore, they are more likely to become self-directed learners to seek more information, pursue further analysis for deep understanding, formulate alternative solutions, and make decision to select the best solution to the problem. Students may soon realize that knowledge is very broad and they have to put their own effort and initiative to learn a particular knowledge for either personal or professional reasons.

2.1.5 P5: Stimulate critical thinking and metacognitive skills

Eeissenger [11] discussed the idea of critical thinking and metacognition in PBL. Metacognition is identified as one of the four basic components of critical thinking, and it is aligned very well with the objectives of PBL. Similar to self-directed learning and lifelong learning, critical thinking and metacognitive skills are not a natural occurrence and cannot be taught, instead, need to be trained through appropriate learning activities. In PBL environment, students regularly engage in critical thinking and metacognition because they are trained to solve real world problem that is challenging, and at the same time they have to fit themselves in the mirror of actual working environment.

Real industrial problems do not have one fix solution with nice integers. Thus, engineering problems designed for PBL implementation must be open-ended. It may have several possible solutions, but there is always the best one. While dealing with open-ended problem, students have to use critical thinking to interpret the problem from different perspectives, identify the existing and new knowledge, seek and learn new knowledge cooperatively to reach deep understanding, identify and evaluate possible solutions, making decision and apply the correct concepts of knowledge to synthesis solution for the problem [12].

Besides, problem should be encountered initially by the students with the only data (or information) available if the real problem is encountered in the actual workplace, and no more. The design of the problem should permit free enquiry so that students by themselves have to identify and obtain the data needed to solve the problem. Another option is that the data can be given abundantly and students have to analyze and extract the only useful one. Such approaches are effective to promote critical thinking and enhance metacognitive skills.

2.2 The Process of Problem Crafting

The design of engineering problems consists of several steps that may require iteration, as described in Figure 2. The process begins with identification of the intended learning outcomes *(STEP 1)*. The gap in knowledge and skills in a problem should not be too big; otherwise, students may just resist and give up. If the gap in knowledge is large (i.e. if it takes more than 2 weeks for the students to solve the problem), it is advisable to break the problem into parts that will require deliverables before the final solution. Other than preventing last minute work, breaking down the problem into parts of phases will prevent students from being overwhelmed, especially if they were facing PBL for the first time. The process continues with identification of the real problem, work setting and demand at the workplace where the learning outcomes fit *(STEP 2)*. In this case, having opinion from industrial experts is very much encouraged.

Then, the first draft of problem is written (*STEP 3*). Problem must be presented in the same format as it is found in the professional practices. One way to do this is by setting a scenario that is plausible. If possible, details for time, location, specific post as industrial practitioner in a company, job specification and people may be used in the problem scenario to aid immersion, engagement and motivation for deep learning of the intended learning outcomes. Problems can be given in the forms of memo, dialogue, letter or e-mail. It should be written using present tense. The problem must contain objective rather than interpretive data, and require students to make response instead of answering a series of questions.

Solution guidelines that include possible answers and learning issues that should arise are prepared to avoid students' learning going off-track *(STEP 4)*. In addition, grading rubric for a particular problem should be prepared ahead of time and given to the students to show them the outcomes and expectations of the problem that need to be achieved. Packaging problem for presentation is an added-value for the problem to aid engagement and immersion *(STEP 5)*. Data and calculation sheets with mock company headings can lead to a more realistic feel. Once problem is crafted, it needs to be reviewed, revised and refined to ensure that it is solvable and can be solved by the students in a the given timeframe *(STEP 6)*. Getting feedbacks from colleagues teaching the same course is necessary before the problem to be distributed *(STEP 7)*.

Figure 2. Steps in crafting engineering problems

3. How to Organize Problems for PBL Curriculum?

If the course consists of a series of problems for students, different scenarios may be used to provide different views of industries and/or different roles that they may play once they enter the workplace. The scenarios of the problems should be structured such that each of them will bring the students up to a higher level of expectation in term of knowledge, cognitive levels and skills as learners, as well as professional achievement and demands at the workplace as engineers.

According to constructivism [1] and SOLO taxonomy [13], learning grows cumulatively in stages in which the learned content is increasingly complex. This is how problems in PBL curriculum in a course may be arranged. Each problem is built upon the previous to develop and bring up students' cognitive ability as well as knowledge. In other words, learning issues for the problems are connected; the content learned in the previous problem becomes the basis for extending new knowledge needed for the current problem. Besides promoting deep learning for all learning outcomes, this approach may also help the students to see that knowledge are not isolated, instead, integrated between one another and exist as a whole. Therefore the ability to reflect and generalize the knowledge learned is crucial.

As the learning outcomes are getting difficult and significant, demand at the workplace should be enhanced as well, for instance from simple task to a big project. It should correspond to the job specification of the assigned role as industrial practitioners. It is expected that after solving several problems through a series of PBL cycles, students will transform from "novice" engineering problem solvers to "experts" within the course duration. This idea of organizing problems in a one-semester curriculum is shown schematically in Figure 3.

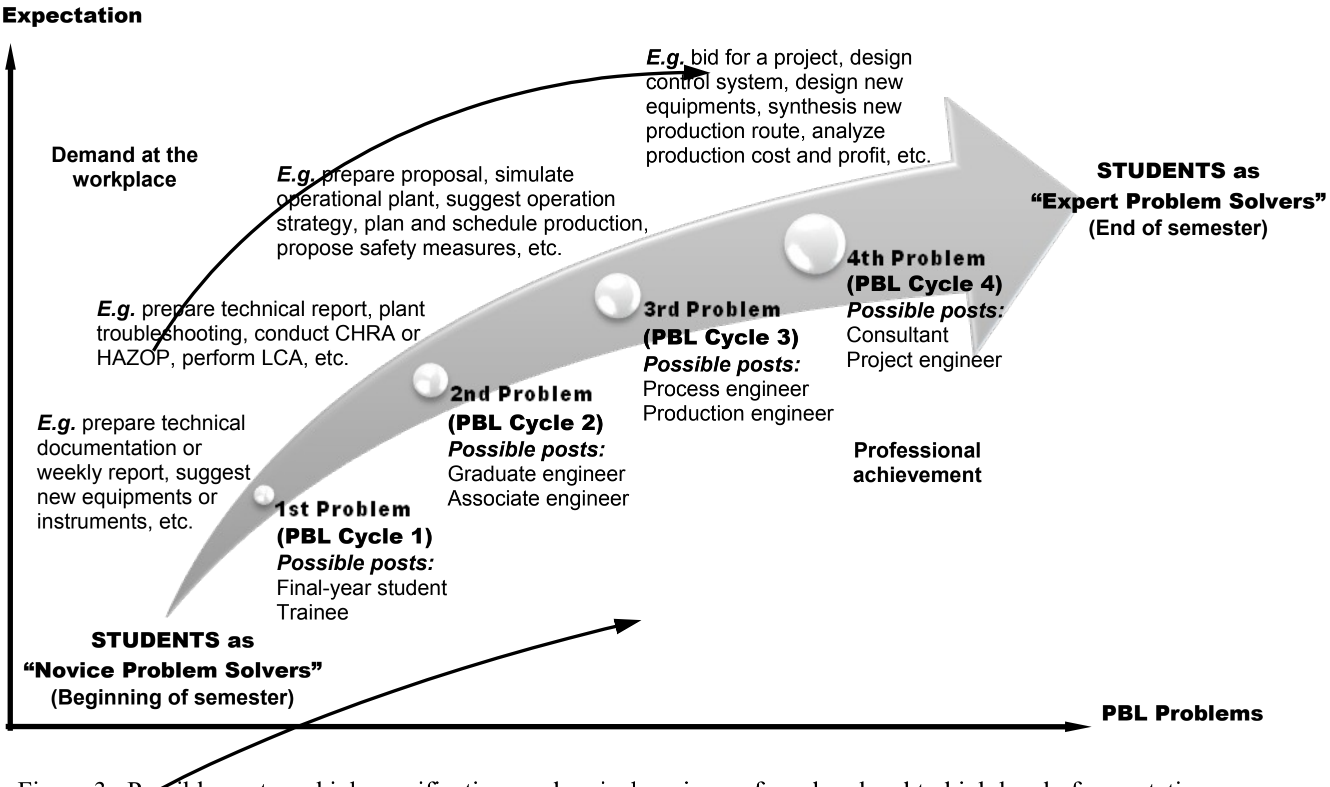

Figure 3. Possible posts and job specification as chemical engineers from low level to high level of expectation

4. PBL in Chemical Engineering – Process Control and Dynamics

Process Control and Dynamics is a three-credit hour course for third year chemical engineering undergraduates at the Department of Chemical Engineering, Universiti Teknologi Malaysia (UTM). The course typically has 30 to 40 students in a class. In this course, students are assigned to learn in small cooperating learning groups (three or four students in a group) in which their learning is guided by one or more floating facilitator during class hours. Around 90% of the course outcomes are covered by means of four PBL problems (or case studies) given throughout the semester. This means that students go through four PBL cycles throughout the semester. A detail description on the PBL model implemented for this course can be found in Khairiyah et al. [2].

The course deals with analysis of chemical processes, mathematical modelling and analysis of process dynamics, tuning PID controllers and analysis of dynamic profiles, and design of automatic control systems. Students need to understand and visualize a process in operation, and relate mathematical theories to the physical reality. This is the first time that they have to deal with processes in dynamics instead of steady-state. Thus, students need a strong background in engineering mathematics and other chemical engineering concepts, learned earlier, to fully appreciate the course outcomes. Besides, computer packages like Polymath, MATLAB Simulink and Aspen HYSYS are utilized to support students' learning process.

4.1 Sample Case Study

Table 1 illustrates the design of the first case study in Process Control and Dynamics course. The case study is mapped to the five principles of designing effective engineering problems proposed *Section 2.1*. The table also acts as a checklist during problem crafting process.

Case Study 1 is very simple as it only covers basic concepts of course, plus the duration for this particular case study is only one week. Therefore, may not all principles of effective engineering problems can be met at this phase. Referring to the problem scenario, Polystyrene (M) Sdn. Bhd., a hypothetical petrochemical company, is chosen to provide context to the problem. Mr. Iqbal Ridha is also a fictitious factory manager who the students can contact through the electronic forum. In actual fact, the class facilitator and tutor is behind Mr. Iqbal Ridha, discussing and answering students' questions.

With regard to the problem scenario, career fair is an actual annual event organized by UTM. Besides, team interview is an authentic case that has been practicing in industries. On the other hand, the given chemical process is not included in the course outcomes and has never been taught in the previous courses. Therefore, students have to put lifelong learning effort to learn more about the process, instead of depending solely on the given process description. However, some of the equipments inside the process are prior knowledge for the students, which are learned in their previous courses. In addition, students have to think critically while using the given process description because only certain information is relevant to the task. Since this is the first case study and considering students' current profile as amateur self-directed learners, the problem plus the coverage of learning outcomes is considered as complex enough to challenge students' learning.

4.2 Organization of Case Studies throughout the Semester

Currently, the scenarios of the four case studies are structured such that each of them will bring the students up to a higher level of expectation. In the first case study, the scenario is tallied to the students' current profile as third-year students who will be going for an interview session at a petrochemical company to get a place for internship. The technical difficulty of this first case study is not very high as it covers the analysis of simple chemical processes, classification of process variables and identification of basic control structures.

In the second case study, the students are now trainees in a chemical plant at the company where they apply for internship as in the first case study. The technical difficulty is now higher, as the problem covers mathematical modelling and analysis of dynamic processes. Usually, this case study is set in a way such that they have to derive a dynamic model of a process in order to determine the dynamic response of a variable due to certain changes in the process.

In the third case study, the students are now graduated and hired to work as chemical engineers that in charge of process control of a chemical plant, which probably similar to the previous case studies. The level of difficulty is now higher and the students are required to perform experiments in the laboratory, or run the dynamic simulation of the chosen process to perform model estimation, stability analysis and controller tuning.

Finally, in the fourth case study, the students become consultant engineers in a process control consulting firm or service company. In the final case study, the students are assigned to design an automatic control system as part of a bidding effort for a section of a real chemical plant. Arrangement with the corresponding company is made ahead of time to get the process description and a basic P&ID, which may or may not be really accurate. Because of the high number of students taking the course, only one representative from each team is allowed to go on the plant visit, where they will ask questions to get additional information on the process. The mock bidding event is held at the lecture hall where students have to open booth and display the control system design on a poster. In addition to lecturers, engineers and plant personnel from the company are invited as judges to evaluate students' design. The best teams are given certificates from the company.

In presenting the series of problems to the students, the amount and type of data and information given are also varied. In some cases, more information than necessary is given, while in some others, there are hardly any, and the students have to think and ask what is the actual information needed. Although students get frustrated when they first encountered the different scenarios, with appropriate facilitation, scaffolding and motivation to support them, they usually begin to enjoy the challenge, especially in the second half of the semester. In fact, it is common for students to go beyond the class syllabus in the final case study.

Table 1. Mapping of the learning outcomes to the respective case studies

Step	Description	Principles
Learning outcomes	*It is expected that students are able to:* • identify chemical processes from a system approach • identify and classify variables in chemical processes • describe basic control structures, identify control variables and their application	
Duration	1 week	
Level of difficulty	Basic	
Type of problem	Authentic	
Scenario	Third-year students who will be attending an interview	
Demand at workplace	Simple technical report for evaluation during the interview session	
Resources needed	Simple chemical process, P&ID and process description	
Recommended approach	Describe a process from system point of view	
Packaging the problem for presentation	Form of delivery - official letter Additional packages : - context time, place, company and people - company logo, letter head, etc.	
Draft	*The scenario:* Polystyrene (M) Sdn. Bhd., located in Pasir Gudang, is one of the largest producers of polystyrene in South-East Asia. In the company, polystyrene is produced from toluene, which is converted into benzene, ethylbenzene and styrene monomer through a series of complex processes. Finally, styrene monomer is polymerized to produce polystyrene. Currently, Polystyrene (M) Sdn. Bhd. is offering a place for a team of undergraduates to attend their industrial training program. In order to recruit the best candidates, the company had taken part in the 2009 Career Fair which was held during the university semester break. For those interested, they were required to submit their resume. The selected students would be put in a team and called for a team-interview at the company later on. You and your friends did not want to miss the chance. One day, you and your friends received an offer letter from the company to attend a team interview with regards to the industrial training program.	Context of the problem
	The letter: The selection committee of Polystyrene (M) Sdn. Bhd. is very interested in interviewing your team for the opportunity to undergo industrial training at our company. The **interview** session is scheduled on 28th December 2009, from 10 a.m. to 12 noon, in the meeting room, Human Resource Department, Polystyrene (M) Sdn. Bhd.	**P1**
	With regard to the interview session, we would like you to demonstrate your understanding on one of our processing plants, the **HDA Process**, in a 3-5 page report.	**P4**
	Please systematically **describe the process from a system's point of view**. Be sure to include the input and output variables involved in the process. **Explain all the automatic control systems**: *classify the variables, identify the control objective, and identify the control configuration used for each control loop. Please comment if the control configurations used are sufficient to tackle the disturbances.*	**P2+P3+P5**
	Enclosed are the process description and a simplified P&ID of the HDA Process for your reference. The interview will be conducted mainly based on the report you will be submitting.	Added value to the problem
Prior knowledge	- Chemical engineering unit operations (second-year course) - Chemical reaction engineering (second-year course)	

Notes:- **P1**: authentic and realistic, **P2**: constructive and integrated, **P3**: suitable complexity, **P4**: promote self-directed learning and lifelong learning, **P5**: stimulate critical thinking and metacognitive skills

5. Feedbacks from Students

Feedbacks from students, taken from their end of semester meta-reflection, on PBL problems (or case studies) are shown in Table 3. Each feedback signifies certain element in the five principles of effective engineering problems.

Table 3. Feedbacks from students on PBL problems

Element	Feedback
Provide learning context	*"I think from what I have learnt from the control class, it is a good start for me to **prepare myself as an engineer**. The technical knowledge that I gain from this class is absolutely useful for me especially if I join the process control field one day later."*
Constructive and integrated	*"Besides, it also make me realise that the important of master all knowledge that gained. We need to **integrate all these technical knowledge in order for us to solve real life problems**. This encourage me change my learning style from performance based to the mastery based because I really want to do well as a future chemical engineer."*
Promote self-directed learning and lifelong learning	*"Besides, **as an engineer, we need to always absorb new knowledge because what we learning now is just the basic**. So we need to have the curiosity to explore more knowledge. Lastly, as engineer, there are always problems waiting us to solve. It is obvious that the problems that waiting us won't be easy. Thus, we can't give up easily when facing the problems. In reality, there is no one will teach you one by one. So we need to try our best to work on it."*
Enhance problem solving skills	*"**As for my problem solving skills, there are significant improvements.** The time requires getting to the problem statement gets shorter. This indicates that I know what my problem is and where I should head and what I should do. Even though that is the case, it is rather hard to judge this skill because it is rather abstract. Maybe because of we are to use to the flash drum therefore we know where the problem lies. But the most interesting part is when completing final phase. That is the time where I can connect all the knowledge to one small design. I know where to begin and what to do. For instance, in order to create a new control loop, I actually identified the objective of the control loop before proceeding to other matters. Then I will identify with my team the variables and classify them. Propose a suitable control configuration is then performed. Here is where we will start to brainstorm every possibility of the control configuration in the control loop. Then only we pick the best after the justification and suitability of the control configuration. Therefore, in the nutshell, I would say that **my problem solving skills has been improved comparing with the previous case study!!**"*
Develop metacognitive skills	*"As for verification of knowledge, asking is always my last resort after few time of reading. Whenever I am blur, I will read more than one material in order to get the real message. But if I am still blur, then I would seek help from my team mate and also other class mate. But most of the time, as I read and read, **I have started to ask myself why**. I don't know whether this is what they call critical thinker or what but this really vivid after CS1. **I started to ask the why question**. It definitely helps me a lot. I started to be able to answer other questions especially on the feedback controller mode. Each equation means something where the integral and the differentiation sign and the position of time constant will results different answer. For example, the time constant for PI mode where it is located at the denominator, as the value gets larger the integral mode will get smaller. That is why I am able to answer a question thrown by classmates during the overall class discussion."*
Open-endedness	*"Now, I don't simply accept or follow the majority answer but to have my own justification and reasons behind everything that I do. Now, **I realize that one problem will have one best solution instead of one answer**. There might be other ways to tackle the problem but it is up to us to evaluate the suitability and the need of it based on our previous knowledge and justification."*
Motivate for deep learning	*"I have realized that, learning process is not about getting the right answer, but it is actually the **process where you gain your knowledge, understand it eventually and demonstrate it by solving the problem.**"*

6. Conclusion

It is no doubt that crafting PBL problems for engineering curriculum is a challenging task. Nevertheless, it still can be done. This paper has described a guided technique to craft effective engineering problems based on five principles: 1) authentic and realistic, 2) constructive and integrated, 3) suitable complexity, 4) promotes self-directed learning and lifelong learning, and 5) stimulate critical thinking and metacognitive skills. To demonstrate the problem crafting technique, sample problem and arrangement of problems for a chemical engineering course is presented. For PBL curriculum, a series of problems should be organized such each of them will bring the students up to a higher level of expectation in term of knowledge, cognitive levels and skills as learners, as well as professional achievement and demands at the workplace as engineers. Feedbacks from students' meta-reflection illustrate that they are benefited so much by the case studies in term of motivation to learn, development of appraisal skills and perspective as engineers.

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