

Crafting Effective Engineering Problems for Problem-Based Learning: Universiti Teknologi Malaysia Experiences

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Abstract

In Problem-Based Learning (PBL), complex, real-world and ill-structured problems are used to motivate students to identify and research the concepts and principles they need to work through those problems. It is the key point to implement a successful PBL instruction. However, crafting a good PBL problem is a challenge for instructors in most disciplines including engineering. Typical problems do not foster the development of effective problem-solving and analytical skills nor do they challenge students to develop critical thinking skills and logical reasoning. With the exception of a few disciplines, good PBL problems usually do not appear in textbooks. As a consequence, an instructor needs to create or find problems, modify textbook problems, or write new problems that address the course objectives and learning outcomes. Crafting quality problems are very important for the full benefits of PBL to be realized. Due to instructors' own learning in the traditional education curriculum, most instructors tend to craft problem based on their subject expertise. This violates the multi-disciplinary richness that PBL advocates. Being able to craft quality and good problem becomes a critical skill for instructors in PBL. This paper aims to describe how to craft effective engineering problems for PBL based on our experiences implementing PBL in Universiti Teknologi Malaysia.

Keywords: Problem Crafting; Effective Problems; Engineering Education; Problem-Based Learning; UTM Experiences

1. Introduction

The aim of the engineering education is to get students to develop the functioning knowledge which allows them to integrate academic knowledge base (declarative knowledge), skills required for engineering profession (procedural knowledge) and the context for using them to solve engineering problems (conditional knowledge), [1]. In order to acquire this integration to achieve the aim of education, the traditional way of teaching and learning has to be put aside and replaced by Problem-Based Learning (PBL), [2].

PBL techniques help students develop the above skills necessary in order to succeed in their post university careers. Students in PBL courses are challenged to "learn to learn" so that they can achieve their highest potential in their chosen professions. Students work cooperatively in groups, seeking solutions to "real world" problems by asking and answering their

own and their peers' questions. In helping to teach each other, students achieve a high level of comprehension of the concepts of the course.

PBL is an instructional method characterized by the use of "real world" problems as a context to learn critical thinking, problem solving skills, and acquire knowledge of the essential concepts of the course. The underlying principle in PBL is "all learning begins with a problem". The problem provides the direction of learning, the motivation for learning and the application of learning. [3,4,5]. The appeal of PBL is its enormous potential for developing understanding since encapsulated in the PBL are explicit expectations that students:

- explore knowledge concepts within different contexts;
- articulate what they already know about a problem (prior knowledge)
- identify and then find information in respect to what "they don't know";

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- specify how new information connects with prior knowledge;
- share and test the viability of new conceptions; and
- reflect how they personally constructed knowledge and became meaning makers (meta-cognitive).

In PBL, the problem acts as the trigger that drives learning. Being able to craft quality and good problem becomes a critical skill for instructors in PBL. This paper aims to describe how to craft effective engineering problems for PBL based on our experiences implementing PBL in Universiti Teknologi Malaysia.

2. Effective Engineering Problems for PBL

In PBL, the problems form the stimulus for learning. It represents the challenge that the students will face in their professional practice when they graduate. The problem provides the motivation and thrust for learning. The problem should allow the students to integrate across the various disciplines.

A problem is thus a critical feature of PBL because students are confronted head-on with a trigger that has seemingly no rules, structure, links or direction. The rationale lies in echoing how students learn so that they question their own learning strategies and processes. A well-designed problem can be a powerful trigger for students' exploratory learning but it is not always easy to write one.

With a good problem, students are then encouraged to think beyond superficial knowledge or mere recall of facts and content. It engages students' interest by motivating them to argue over how to interpret and approach the problem and its embedded issues; it challenges students to review their understanding of information through questioning, probing, drawing links, making reference to prior knowledge and checking assumptions or formulating hypotheses.

In other words, the nature of a problem is such that learners need to unpack what they think they know, and

repack knowledge after a thorough understanding of the ideas and concepts that drive true learning.

There are embedded learning objectives that need to be teased out by the students as they engage with the problem. The whole idea is to achieve a balance between structure and "fuzziness". While there is no formula for writing a good problem, there are some guiding principles in designing effective PBL problems that align themselves with the learning goals in the curriculum you are teaching.

3. Is the Problem Well-Crafted?

In most PBL programs, the goal is to empower the students with the task of creating the learning objectives that are important to them. The well-crafted problem should be posed such that: [6,7]

- The learning outcomes expected by the teacher are identified correctly by the students; the scenario contains "cues" that will trigger the desired search for learning objectives
- The learning outcomes are consistent with the stage of development and builds on and activates prior knowledge
- An appropriate level of complexity is included
- The scenario requires integration of knowledge, skills and attitudes across topics
- The scenario allows an openness
- The scenario is motivational and relevant; the scenario is similar to one we might encounter in professional practice
- The scenario promotes student activity
- The scenario identifies the context, gives a concrete scenario and clearly identifies the expected task

When designing or crafting a problem, several features of the problem have to be considered. These pertain to the problem characteristics, problem context, learning environment and resources, and problem presentation. Table 1 summarizes the issues to be considered relating to the well-crafted problem [8].

Table 1. Features of problem crafting/design (based on Tan-Oon-Seng (2003), *Problem-Based Learning Innovation: Using Problems to Power Learning in the 21st Century*, pp. 87)

Problem feature	Issues to address
Characteristics	<ul style="list-style-type: none"> • What is the real-world relevance of the problem? • What is the curriculum relevance? • What is the level of difficulty? • What is the level of complexity?

	<ul style="list-style-type: none"> • Is it an interdisciplinary problem? • Does the problem call for integration of multiple disciplines (or topics)? • How open is the problem (in terms of possible solutions)? • Does it call for a final product?
Context	<ul style="list-style-type: none"> • Is the problem unstructured (ill-structured)? • Does it trigger curiosity? • Will it motivate ownership? • Does it appear challenging? • Are there sufficient elements of novelty?
Learning environment and resources	<ul style="list-style-type: none"> • How can the problem stimulate collaborative inquiry? • What kinds of independent learning can be incorporated? • What is the extent of guidance needed for using the learning resources? • What kinds of information resources are expected (e.g. library resources, the internet)? • Will field/laboratory work be incorporated? • Will information gathering include interviews and expert's views? • What else might we need to solve the problem?
Presentation	<ul style="list-style-type: none"> • Do we use a problem scenario? • Should it be a short scene or multiple scenes? • Does the problem scenario come with hypertext? • Do we need a detailed case write-up? • Can we use video clips? • Can we use audio news? • Can we do a role play? • Can we simulate a client requirement? • Are there relevant newspaper cuttings? • What about magazine or journal reports? • Are there websites that can be used?

3.1 Reflect Real Work Demands - Start with the End in Mind

Problems form the stimulus for PBL. Problems designed for students in an education should mirror those that the students will encounter in the workplaces to make them real work ready. In education, an authentic PBL requires the student to go through the same activities during learning that are valued in the real world [9]. Hence, instructors should craft problems that help their students attain the exit outcomes expected of their graduates [10]. To prepare students for their professional practice, instructors can formulate a functional map detailing the likely outcomes that the students should be able to perform in their professional careers.

These exit outcomes are articulated and form the organized focus for all staff members and students to master during the course of study. Using a design down approach, exit outcomes are translated to problem outcomes [10]. Achieving these problem outcomes would lead to the exit outcomes. Instructors craft problems to help their students achieve the problem outcomes by solving the problem. These outcomes serve as benchmark for assessing the students' performance.

Effective problems always must be crafted with the end in mind for maximum benefits to future employers and maximum positive impact on society. Instructors are preparing the students for the world of change. Students should be able to hit the road running when they graduate. With these in mind, instructors need to craft problem that mirrors the real world challenges. Problems must be presented in the same format as they are found in the professional practices.

3.2 Constructivist Learning Approach - Problems Must Build on Prior Knowledge

PBL is a powerful philosophy that empowers the students to take charge of their learning agenda. To do so, students must be motivated to solve these problems. The problems must be written in an interesting format that challenges the students to think. The problems should not be disguises of instructions. Instructors should always check to see if their problems are motivating enough to solve from the students' perspective. Problems should provide sufficient opportunities for students to conduct research and study on their own, building on prior knowledge and expanding on associative networks of information. Prior knowledge information is engaged as the student is exposed to a range of diverse situations,

promoting the transfer of knowledge to unique situations presented in the problem.

Problems crafted should be real-life or similar to the situations that students will face when they graduate. Students are motivated more by real-life problems compared with “ivory-tower” problems that they will never face in the real world. Many of the traditional problems in lecture-based teaching are designed to test the understanding of theories and application without direct relevance to the real world. Problems should be as current as possible.

3.3 Enhance Metacognitive Skills – Produce Reflective Students by Setting Challenging Problems

Few problems in everyday life or professional practices present themselves with all the relevant information that is needed to understand them well to make accurate decisions; more information is always needed. Some of the needed information is obtained by investigating the problem, making observations, conducting primary and secondary research, asking questions, probing and investigating. For a student to determine what needs to be investigated or what questions to be asked requires much reflection, thought and deliberation.

Problems that do not present students the opportunities to reflect and deliberate are not thought provoking enough, and will not be effective in a PBL curriculum. The problems must be challenging, unusual, new or perplexing enough for the students to engage their metacognitive level to discover and uncover, to reflect and review, to deliberate and explore, in directing them to the decision path they believe is valid. Only when a student is confronted with a difficult or unexpected or puzzling situation or problem, will the student ask himself such questions as: What am I going to do? How am I going to do it? Did it work?

3.4 Integrate Knowledge Base - Promote Multi-Disciplinary Mindset

Students who study in subject mode tend to see subject expertise as a cluster of neatly divided silos. This way of learning promotes subject arrogance. Students may understand the underpinning knowledge within each discipline but may encounter difficulties in trying to integrate them. If problems are crafted based on subject expertise only, the students will suffer from a myopic mindset. PBL promotes multidisciplinary mindset, through problems that reflect the real work demands that are multi-disciplinary in nature.

4. Example of Problem Crafting: Case Study for Process Control and Dynamics

We have implemented PBL in Process Control and Dynamics course that has a reputation among undergraduate as one of the toughest subject in chemical engineering syllabus [11]. Table 2 shows a case study given to students in the Process Control and Dynamics class in Semester 1 2005/2006.

In this case study, the problem given was a real problem facing by the laboratory of Process Control, Universiti Teknologi Malaysia. This laboratory has just received a new level control pilot plant supplied by PcAutomation Sdn. Bhd. Since the pilot plant was quite new and never been utilized before, we do not have any information to model the process. Therefore, we asked students to develop a mathematical model for this level control pilot plant.

In order to model the process, students have to go to the laboratory to do some experiment. The problem can not be solved just only by gathering information from literatures. Some experimental works have to be done and integrated with information gathered from literatures to model the process. Students group that did not do experiment works will face some difficulty to solve the problem.

Table 2. Case Study of Process Control and Dynamics – Experimental version

		Date: 19 th . July 2005
To	:	Process Engineers Team
From	:	Operations Manager
Re	:	Study the <i>PcA-SimExpert Level Control Pilot Plant</i> for Chemical Engineering Department, Universiti Teknologi Malaysia
Ladies and Gentlemen,		
We have just installed our <i>PcA-SimExpert Level Control Pilot Plant</i> for Universiti Teknologi Malaysia. Level process control is a control system via computer system to monitor the level of liquid in tanks and vessels and to enable automatic adjustments to the level of liquid through mechanical means. Its applications are widely being utilized in plant control and automation throughout the world.		

2. The basic mechanism that is used in real industry is demonstrated in the *SimExpert Level Control Pilot Plant*. This Pilot Plant represents a typical Boiler Drum Level Process found in most industries. Feedwater is pumped from a feedwater tank into the Boiler Drum. Drum Water level is controlled via a feedwater control valve. Two types of level processes have been designed into the pilot plant, namely an Integrating Process and a Self-regulating Process. Simple PID Control of level and Cascade Level Control with Flow control loop are provided for each of the two processes above. Level measurement based on both Open Tank and Closed Tank techniques are provided. The control valve, being one of the most important elements in the control loop, has been careful selection of with proper sizing and valve characteristics. Control valve trim material is made of Stainless Steel for durability. Flow measurement based on common measurement technique for liquid, such as Differential Pressure (Orifice plate) flowmeter, magnetic flowmeter, or Vortex flowmeter is provided depending on user requirements.

3. The model *Sim308L PcA SimExpert Level Control Pilot Plant* is a scaled down Liquid-phase Level-Flow Process Pilot Plant. It is a proven, self-contained unit designed to simulate real processes found in Industrial Plants for the Study of Automatic Process Control for Liquid Level and Flow Processes. Its unique design considerations, including mass balance considerations, allow this pilot plant to be used for either Batch or Continuous operations. All Instrumentations used are of industrial grade. A Local Control Panel (LCP) is included to house an Alarm System, Power Indicators, a Multi-loop Controller, a dual pen process Recorder and operation buttons. All process pipelines and wetted parts are made of stainless steel to prevent the formation of rust which can be detrimental to process instrumentation such as flowmeters and control valves.

4. Your team has to go to Process Control Laboratory at Faculty of Chemical & Natural Resources Engineering of Universiti Teknologi Malaysia to study the process. Before go there, make sure to make an appointment with the lab assistant Mr. Ahmad Kamal Baderon. Once there, your task is to develop the mathematical models for the pilot plant. In your report, include the feedback level control block diagram.

We look forward to the further development of this problem. Give me your report on 26th. July 2005.

Very truly yours,

Rahim Mansur

Ir. Rahim Mansur, Ph.D.
 Operation Manager,
 Pc Automation Sdn. Bhd.

4.1 Is the Problem Well-Crafted? Checklist

In order to know that designed problem for PBL for Process Control and Dynamics class was well-crafted, we did some checklist to compare with features suggested in [8]. From Table 3, we found that our case study satisfied all issues addressed to be an effective and good problem. Our case study is based on real-world-industry problem. The level control pilot plant is a real process found in Industrial Plants for the Study of Automatic Process Control for Liquid Level and Flow Processes. All instrumentations used are of industrial grade. A Local Control Panel (LCP) is included to house an Alarm System, Power Indicators, a Multi-loop

Controller, a dual pen process Recorder and operation buttons.

The designed case study is relevance to the chemical engineering curriculum in term of problem solving, team-working, life-long learning and ethics addressed. It is also need knowledge about unit operation, mass balance and the most important knowledge in differential equation. Students must have these knowledge before they can solve the designed problem.

Another characteristics in our designed case study is there no one final solution for the problem. The model that will be developed by students can be accepted as a solution if they have enough information to verify their claim and be able to depend their solution

Table 3. Checklist for Case Study of Process Control and Dynamics

Problem feature	Issues to address	Our Case Study
Characteristics	a. What is the real-world relevance of the problem?	a. This is real-world industry based problem.
	b. What is the curriculum relevance?	b. Problem solving, team-working, life-long learning, ethics
	c. What is the level of difficulty?	c. Moderate
	d. What is the level of complexity?	d. Moderate
	e. Is it an interdisciplinary problem?	e. Yes

	f. Does the problem call for integration of multiple disciplines (or topics)?	f. Unit operation, differential equation, mass balance
	g. How open is the problem (in terms of possible solutions)?	g. There is no single solution for the model (depends on assumption)
	h. Does it call for a final product?	h. Mathematical model
Context	a. Is the problem unstructured (ill-structured)?	a. Yes
	b. Does it trigger curiosity?	b. Yes
	c. Will it motivate ownership?	c. Yes
	d. Does it appear challenging?	d. Yes
	e. Are there sufficient elements of novelty?	e. Yes
Learning environment and resources	a. How can the problem stimulate collaborative inquiry?	a. Engage group and individual learning
	b. What kinds of independent learning can be incorporated?	b. Data gathering, process modelling
	c. What is the extent of guidance needed for using the learning resources?	c. Primary and secondary sources
	d. What kinds of information resources are expected (e.g. library resources, the internet)?	d. Library resources, internet
	e. Will field/laboratory work be incorporated?	e. Yes
	f. Will information gathering include interviews and expert's views?	f. Yes, students need to ask lab assistant
	g. What else might we need to solve the problem?	g. Process flow diagram
Presentation	a. Do we use a problem scenario?	a. Yes
	b. Should it be a short scene or multiple scenes?	b. Short scene
	c. Does the problem scenario come with hypertext?	c. No
	d. Do we need a detailed case write-up?	d. Yes
	e. Can we use video clips?	e. No
	f. Can we use audio news?	f. No
	g. Can we do a role play?	g. No
	h. Can we simulate a client requirement?	h. No
	i. Are there relevant newspaper cuttings?	i. No
	j. What about magazine or journal reports?	j. Yes
	k. Are there websites that can be used?	k. Yes

5. Conclusion

Problems drive learning in a PBL curriculum. Hence, it is essential that problems reflect the exit outcomes that are mapped out in the curriculum. Problems should be viewed in a holistic manner crossing the boundaries of many subjects rather than as fragmented pieces written to cater to isolated subjects. Problems should be real-world industry-based and not subject-driven. A database of problems that mirror real world demands (and with different levels of difficulties) serves as a rich resource base for learning.

Instructors should craft effective problems that motivate their students and prepare students for the real world by ensuring that their students achieve the desired exit outcomes (generic skills) after they have solved the problems. This is a critical success factor of PBL.

Good and effective problem design for PBL takes into consideration the goals of PBL; students' profiles; problem characteristics: authenticity, curriculum relevance, multiplicity and integration of disciplines; the problem context: ill-structuredness, motivation of ownership, challenge and novelty; the learning environment and resources; and problem presentation.

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