AC 2011-2720: AN INSTRUMENT TO ASSESS STUDENTS' ENGINEERING PROBLEM SOLVING ABILITY IN COOPERATIVE PROBLEM-BASED LEARNING (CPBL)

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An Instrument to Assess Students' Engineering Problem Solving Ability in Cooperative Problem-based Learning (CPBL)

Abstract

The development of an instrument that can be used to study students' ability in their problem solving skills while undergoing cooperative problem-based learning (CPBL) in engineering classrooms is reported. The instrument combines Philip's flowchart of traditional engineering problem solving model which was divided into definition, strategy and solution phases, with Hmelo's components of problem solving assets which are knowledge, perception and cognitive processing. The instrument consists of 24-self-report items which require students to indicate the degree of their problem solving skills across the following domains: problem identification, problem analysis and synthesis, and solution generation. The instrument also measured students' ability in conducting self-directed learning and reflection, which are very important elements in developing and enhancing problem solving skills. The instrument shows the degree of students' problem solving process skills, whether they usually take the surface or deep approach. A sample study is performed on a group of students in a third year engineering class which use CPBL as the teaching methodology, and is reported in this paper. The instrument had been validated by experts in problem solving and cooperative problem-based learning. The overall reliability of the instrument is considered high with Cronbach alpha of 0.94.

Introduction

Engineering schools today are facing challenges they have never faced before. Today's engineers are entering into a world marked by rapid and global change. Factors such as technological advancements, the need to be able to resolve problems quickly, the ability to consider open-ended problems, the ability to cope well under information overload, etc., put future engineers under unfamiliar pressure. The only way to cope with this pressure efficiently is through acquiring advanced thinking and problem solving skills. Thus, there is an urgent need to prepare future engineers for solving unknown problems. The emphasis should be on teaching to learn rather than providing more knowledge. Teaching engineers to think analytically will be more important than helping them memorize theorems. Teaching them to cope with rapid progress will be more critical than teaching them all of the technology breakthroughs.[1] In the opinions of engineering managers, thinking and problem solving skills are evaluated as the most important skills of an engineering professional, and are becoming even more vital in the extremely challenging world of today.[2]

Currently, most of our engineering schools have developed curricula by creating scenarios or predicting the expected problems. In doing so, the focus is more on knowledge rather than skills. According to Bransford, curricula based on specific knowledge are built from the bottom up.[3] Engineers whose education is built from the bottom up cannot comprehend and address big problems[1]. The future engineering curricula should be built around developing skills and not around teaching available knowledge. The focus must be on shaping analytic skills, design skills and problem-solving skills. Engineering educators must teach methods and not solutions.

Even if problem solving is taught to engineering students, it is taught in a way that is contrary to real life practice in engineering. Almost all the time engineering students are taught to solve well-structured problems with a single solution, which are inconsistent with the nature of the problems they will need to solve in their real life practice as engineers.[4] Well-structured, closed problems that are amenable to a single correct solution are at one end of spectrum, and ill-structured, open-ended problems that are not amenable to such a solution, are at the other end.[5] The discrepancy between what learners need (complex, ill-structured, one-ended problem-solving experience) and what formal education provides represents a complex and ill-structured problem.[6,7]

Cooperative Learning (CL) and Problem-based Learning (PBL) are said to be the teaching methodologies used in response to the challenges posed by today's educational outcomes.[1, 6, 7, 8] In CL, students work together in a small group to accomplish a shared learning goal and to maximize learning.[9] In PBL, besides promoting the construction of knowledge, it also contributes to the development of problem solving skills and attitudes deemed important for engineering practice.[8] Today's students need to be engaged in constructing their own knowledge structures and learning environments through interaction and collaboration. Prince recommended that CL and PBL be integrated to exploit the natural synergy between them.[10] Khairiyah et. al. put forth a model that is a hybrid of CL and PBL, called Cooperative Problem Based Learning (CPBL). The model incorporates CL principles into the PBL cycle to guide the development of learning teams in forming and enhancing learning and problem solving skills. A detailed description of CPBL and its implementation can be seen in Khairiyah et. al.[11]

This paper discusses the Engineering Problem Solving Instrument (EPSI) that was designed to measure the extent of deep thinking in problem solving after undergoing CPBL. The EPSI was designed based on concepts of engineering and technical problem solving derived from the literature suited for the CPBL environment. The instrument follows the style of Woods' My Role Is Questionnaire (MRIQ) to provide a contrast as well as continuity between deep and surface learning approaches.[12] A case study on the usage of the instrument to measure the extent of problem solving ability of students after undergoing CPBL is also included.

Review of Concepts for Developing the EPSI

This section contains brief descriptions of the important concepts applied in the study. It is then followed by discussion about development of engineering problem solving skills instrument.

Engineering Problem Solving Skills

There are four approaches in the development of engineering problem solving skills. The first is the topology of problem solving. [6, 13, 14, 15] The second is to the design of assessments that test the skills.[16,17,18, 19]The third is learning problem solving with the use of heuristics[20, 21, 22, 23, 24]. The forth approach is the difference between novices and experts or the surface versus deep thinkers in problem solving.[25, 26, 27, 28, 29]

Problems vary in their nature, in the way they are presented, and in their components and interactions among them. Mayer and Whitrock described problems as ill-defined-well-defined and routine-non-routine.[14] Jonassen distinguished well-structured from ill-structured problems and articulated differences in cognitive processing engaged by each.[6] Strobel mentioned about the essential of understanding problems and problem solving in order to better design problems, and better design support structures for students engaging in PBL.[13]

It is well accepted that the mode of assessment influences learning. Traditional assessments did not encourage the development of ill-structured problem solving skills. In order to assess problem solving skills, Woods and his colleagues devised questions that enable students to display the processes they use to solve problems.[17] They also made evaluations of attitude and skill towards lifelong learning. Rustin assessed his engineering students by allowing the examination to be taken during a period of several days to condition his students to be dependent on the library.[19] Since there is usually no single preferred solution, Rustin evaluated his students in detail, including the reasonableness of assumptions and value judgments made. In terms of difficulties in writing examination questions, Carter had made significant attempts to direct his students' answers into more detailed engineering analyses of problems set.[18] The problems were modified to consider not only engineering devices, but also engineering situations, and methods of achieving solutions under a variety of constraints.

The reason for teaching heuristics is based on the principle that if a learner knows the steps involved in problem solving, the learner's performance in problem solving will be improved. One of the best known problem solving heuristic is due to Polya which was used by Fuller and Kardos in engineering problem solving education, known as Polya Maps.[30, 31] Woods and his colleagues at McMaster modified Polya's heuristic for their engineering problem-solving course at McMaster University called MPS.[16, 17] The MPS is a separate, stand-alone, institutionalized program, where it distributed problem solving "workshops" throughout the program, i.e. in year 1, 2, 3 and 4. Unlike MPS, the Cooperative Problem Based Learning (CPBL) heuristic model is expected to develop problem solving skills when students are learning contents in a course.[32,33] It is under the sole control of a lecturer (facilitator), without necessarily institutionalizing the approach in the course syllabus. Because of the flexibility of the CPBL model, the outcomes of a course can be formulated as desired.

When considering maturity in thinking and meta-cognitive activities on problem solving, several approaches have been suggested. Among them are Bloom's taxonomy, SOLO taxonomy, Chi's experts versus novices, and Piaget's assimilation versus accommodation.[25, 34, 35] They are a number of characteristics that differentiate the experts from the novice problem solvers. The most familiar distinction is that the experts think about, consider, and examine the problem as a whole before beginning to work on a solution. They classify a problem according to its underlying principles, deciding to what class of problem it belongs. They engage in a planning stage before attempting a solution. On the other hand, the novices jump right into finding the solution.[27, 29] Biggs and Tang classified five cognitive levels in what is known as the SOLO taxonomy.[26] The five levels include the pre-structural at its lowest level, followed by uni-structural, multi-structural, relational and extended abstract.

Engineering Problem Solving Process

They are many ways of presenting steps taken in problem solving process. Polya in his model, identified four stages, which are understand, plan, carry out and look back.[30] Wales and his colleagues had identified six steps taken by experienced decision makers.[36] The steps are defining the situation, state the goal, generate ideas, prepare a plan, take action and look back. Eck and Wilhelm listed the engineering problem solving process in this way: (1) problem identification, (2) information gathering, (3) statement of objectives, (4) identification of constraints and assumption, (5) generation of solutions, (6) analysis, (7) Synthesis, (8) evaluation of alternatives.[37] Woods and his colleagues used the six-step model.[17] These were: (1) engage, I want to learn, (2) define the stated problem, (3) explore, (4) plan, (5) do it, and (6) look back.

Researchers and engineering educators frequently refer to similar information through differences in terminology, sequence, and detail. In general, engineering problem solving process can be divided into three foundational phases; the definition phase, the strategy phase and the solution phase.[38] The definition phase is where problem solvers try to identify all the unknown and known information related to the problem, scope or the problem, learning issues, constraints and limitation. The strategy phase is where problem solvers apply the information gathered from the problem definition to the problem through generation of several solution alternatives by collection, testing, analysis, and synthesis of data based on the specific problem and related constraints. The solution generation phase is where problem solvers interpret the results of the analyses, and synthesis them to select and recommend solution to the problem.

Each of these phases represents a general overview of the engineering problem solving process. Effective problem solvers understand and apply each broad phase described above includes a series of actions. At the same time, the foundational phases of problem solving serve as critical anchors for more detailed activities required for effective solutions. One consistent feature of engineering problem solving is that of iteration. Figure 1 shows the three foundational phases of problem solving in relation to the traditional series of detailed procedures and actions commonly used in engineering problem solving process (Modified from Phillips).[38]

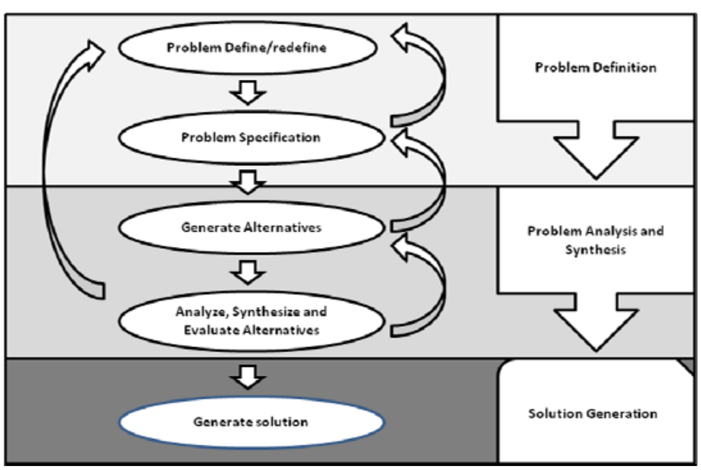


Figure 1: The Engineering Problem Solving Process (modified from Philips)[38]

The Problem Solving Assets

Researchers have identified many important problem solving assets and have used several different schemes for categorizing these component assets. Mayer and Whitrock divided assets into two groups, *knowledge* and *cognitive processes*.[14] Mayer's structure of "knowledge and processes" or "knowing and doing" covered all the assets needed to solve any sort of problem and did not imply significance to one over the other. Crucial to solving, the division clarified elements such as meta-cognitive knowledge and meta-processing, which often get lumped together but had much different impacts on problem solving. Adams had made one change to Mayer's structure.[39] Beliefs and expectations were extracted out of the knowledge section and placed along with motivation in an additional category. The divisions were made based on what problem solvers bring with them to the problem i.e. knowledge, processes, with beliefs, expectations and motivation in between. When formulating a mental representation of the problem, solvers use facts and concepts that they believed apply to the problem. While planning and monitoring the progress of the plan, solvers used problem solving strategies. When executing the plan, solvers used the procedural knowledge that they've learned which applies to that specific topic. Beliefs, expectations and motivation are located between knowledge and processes because they shape all of a student's cognitive processes. It mediates how and which knowledge items will be used.

Knowledge is something that we have. It consists of factual knowledge, semantic knowledge, procedural knowledge and strategic knowledge. Beliefs and expectations include many different ideas about what students expect and what they believe are important or useful about self (including meta-cognitive knowledge) and about the problem. There are many different reasons of motivation. It could be internally, externally, strongly, weakly, positively or negatively motivated. Cognitive processing is something we do while engaged in productive problem solving.[39]

Novices versus Experts Problem Solvers (Surface versus Deep Learners)

Problem solving engages higher-order thinking skills and is believed to be among the most authentic, relevant, and important skills that learners can develop.[15] When considering maturity in thinking and meta-cognitive activities on problem solving, several approaches have been suggested. Among them are Bloom's taxonomy and SOLO taxonomy.[25, 34] Bloom and his colleagues identified six levels of learning known as the Bloom's taxonomy of cognitive domain. The six levels include the knowledge or recognition of facts at its lowest level, then comprehension, application, analysis, synthesis, and evaluation. Colleagues of Bloom's, revised the taxonomy, reorganizing some of the categories and turning the nouns of Bloom's taxonomic levels into verbs with remembering at its lowest level, then understanding, applying, analyzing, evaluating and creating. Novice problem solvers usually use remembering and understanding, while experts usually exercise the top three levels of Bloom's taxonomy. The first two are considered as surface learners and the top three are deep learners. Biggs and Tang classified five cognitive levels in what is known as the SOLO taxonomy of the cognitive domain.[25] The five levels include the pre-structural at its lowest level, followed by uni-structural, multi-structural, relational and extended abstract. Biggs called the lowest two levels of problem solvers as surface learners and the top three as deep learners.

Cooperative Problem-Based Learning (CPBL)

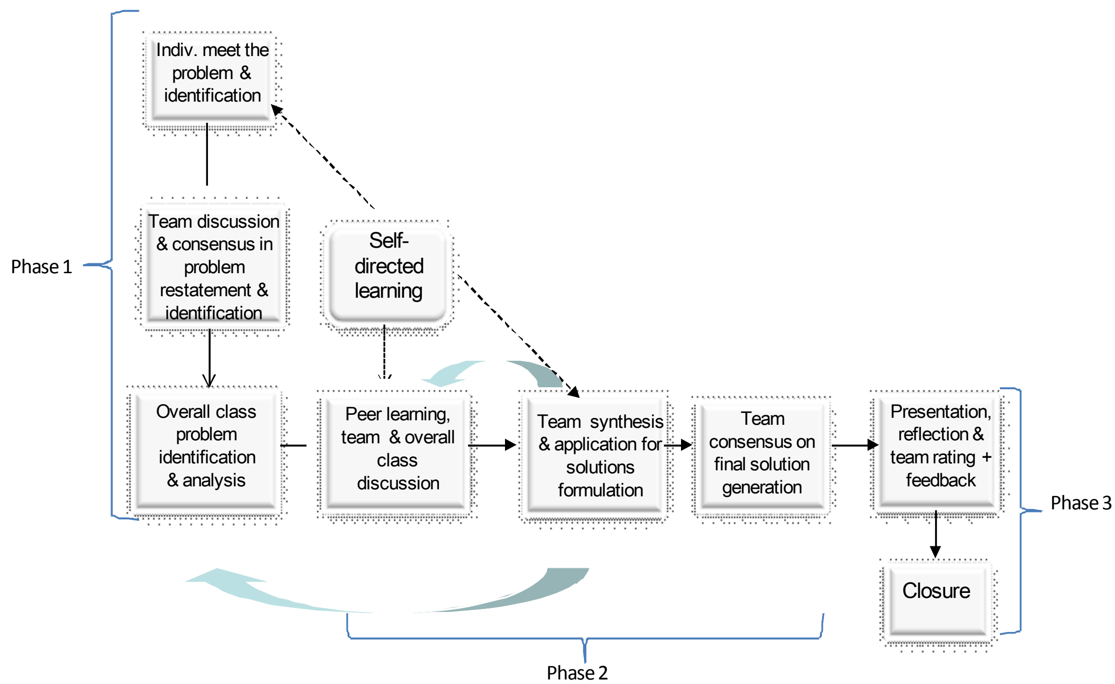
The CPBL model is a combination of PBL and CL to emphasize learning and solving problems in small student teams (consisting of 3-5 students) in a medium sized class, of up to 60 students for one academic staff taking the role of a floating facilitator. Since supporting and monitoring students' learning by a floating facilitator can be challenging in a typical class, the CL aspects is integrated to encourage accountability, cooperation and peer-based learning as well as monitoring and support. CPBL requires the problem to be realistic, if not real, with a scenario that serves to contextualize and immerse students in the problem.

CPBL is underpinned by constructivism[7]. The model emphasizes participation of students learning together in their team as well as in the learning community developed in the learning environment of the classroom. Students are engaged to learn through solving an authentic problem which has a scenario that ties the concepts learn to possible applications in the real world. The CPBL cycle framework as well as the activities described in the framework is used as scaffolding for going through the process of finding a solution to the problem given. Students are guided using the framework as they go through the CPBL cycle several times, with the instruction and description fading out as they gain confidence and expertise to solve the problem on their own.

In CPBL, the problem crafted serves to engage students to learn new knowledge through solving the problem. The problem, therefore, is designed to encompass the content outcomes in the context of the function of the knowledge in the discipline. The realistic (or real) problem must be contextualized in a scenario that students can be immersed in. Providing context will actually reveal to learners the importance of the knowledge learned, as well as the situation in which the knowledge is applied. This provides a purpose and motivation, and consequently engages learners. Other than using new knowledge learned, the problem should also contain knowledge known to the learners, which will serve as familiar territory or spring board that students can start from to extend their knowledge into new territory. Thus, a realistic, contextualized, unstructured problem provides knowledge centered as well as learner centered aspects of the CPBL learning environment.

Figure 2 illustrates the CPBL framework for learners which serve as scaffolding to guide through the whole CPBL process. Referring to the framework, there are 3 phases in the CPBL cycle. Phase 1 consists of the problem identification and analysis stage. Phase 2 is the learning, application and solution formulation stage. Phase 3 is the internalization and closure stage. Activities represented by each block in the three phases are designed to assist students in explicitly learning and developing skills as they go through the CPBL process.

The framework was designed based on Bigg's constructive alignment which emphasized on employing learning and assessment activities that are aligned to the learning outcomes.[25, 26] The blocks in each phase of the framework explicitly spells out the learning and assessment activities to attain outcomes, which in turn support the overall outcomes of CPBL. It was designed to fulfill the five principles of cooperative learning as defined by Johnson, Johnson and Smith which are positive interdependence, individual accountability, face to face interaction, appropriate interpersonal skill and regular assessment of team functioning.[9] A more detailed description and mapping of the activities in the framework to the five principles can be seen in Khairiyah et al. [33]



*Insufficient understanding of learning issues to solve problem
** Incomplete or misunderstanding of problem requirement

Figure 2: The Cooperative Problem-based Learning (CPBL) Framework

Development of Engineering Problem Solving Instrument (EPSI)

Designed based on engineering problem solving concepts derived from the literature, the Engineering Problem Solving Instrument (EPSI) was developed to measure improvements in problem solving ability as perceived by engineering students upon going through CPBL in a course. The instrument was designed to gauge the enhancement of problem solving skills as defined by Jonnesen, Woods and Mayer. Unlike past assessments, such as those developed by Woods, Ruskins and Carter, this assessment was developed not as a means to measure the ability of problem solving enhancement per se. It is a self-evaluation instrument to see whether there are significant improvements in problem solving skills among engineering students who had undergone CPBL.

Table 1 shows a summary of the literature related to the engineering problem solving skills which was discussed in the previous section. From the literature shown in Table 1, essential and suitable concepts were further extracted to form a basis for developing the EPSI. These concepts were selected based on their suitability to the CPBL goals and process. A summary of the essentials related to the design of the EPSI is shown in Table 2.

Table 1: Summary of the Essentials Related to Engineering Problem Solving

Literature Review	Concept	Category
Jonassen [6] Mayer and Whittocks [14] Strobe l[45]	• Ill-structured verses well-structured • Ill-define verses well-define and routine-non-routine • Emphasize important of different support structure for different problem topology	**Problem Topology**
Woods [17] Ruskins [19] Carter [18]	• Devised questions that that display students' problem solving process • Devised assessment for taking long exam duration, no single answer • Devised questions to answer engineering analysis, not devices, but situation.	**Design of assessments to test the skills**
Fuller and Kardos [31] Woods [16]	• Polya Maps (based on Polya's mathematic problem solving, applied to engineering) • PBL – MPS (McMaster Problem Solving) using PBL to teach engineering problem solving yearly.	**Heuristics**
Bloom [34] Biggs and Tang [25] Piaget [35] Chi [27]	• Bloom's taxonomy – remembering, understanding, applying, analyzing, evaluating, creating • SOLO taxonomy - pre-structural, uni structural, multi-structural, relational, extended abstract • Assimilation versus accommodation • Experts versus novices	**Maturity in thinking**
Polya [30] Wales [36] Eck and Wilhelm [37] Woods [17] Phillips [38]	• understand, plan, carry out and look back • defining the situation, state the goal, generate ideas, prepare a plan, take action and look back • problem identification, information gathering, statement of objectives, identification of constraints and assumption, generation of solutions, analysis, synthesis, evaluation of alternatives • engage, define the stated problem, explore, plan, do it, look back • definition, strategy, solution - with iteration in between	**Problem Solving Process**
Mayer and Whitrock Adams [39]	• Knowledge and Cognitive processes • Belief-motivation-expectation in between	**Problem Solving Assets**
O'Donnell [41] Savery [40, 46] Hmelo and Barrows [42, 43] Woods [16, 17, 21] Johnson, Johnson and Smith [9]	• CL - Social constructivism • PBL - Constructivist • PBL - Medical • PBL – Engineering • CL principles	**CL and PBL**

Table 2: Summary of the Essentials Related to the Development of EPSI

Category	Concepts Related to CPBL	Literature Review
Engineering Problem Solving Skills		
Topology	All problems posed are ill-structured, open-ended	Jonassen , Mayer and Whittocks [6, 14]
Design of instrument to gauge students' problem solving enhancement	Self-evaluation on students' problem solving skill enhancement upon attending CPBL	
Heuristics	Applying MPS concept, but in a course instead of institutionalized 4 stages = 4 problems	Woods [17]
Maturity in thinking	Scale for selection in the instrument based on surface learning as option 1 and deep learning as option 2	Biggs and Tang, Piaget, Chi [25, 27, 35]
Engineering Problem Solving Process	Using general engineering problem solving cycle, incorporated with important elements in CPBL cycle. Becomes constructs for the development of the instrument. The elements are: Problem solving cycle: Problem identification Problem analysis and synthesis Solution generation Important elements of CPBL cycle: Reflection Self-directed learning	Phillips [38] Khairiyah [33]
Engineering Problem Solving Assets	The detail elements in each constructs are designed based on knowledge, belief/expectation/motivation and process	Adams [39]
CPBL	The instruments is designed for CPBL – a hybrid of CL and PBL • CL - Social constructivism • PBL - Constructivist • PBL – Engineering • CL principles	O'Donnell [41] Savery [46] Woods [21] Johnson, Johnson and Smith [9]

In defining the constructs of the instrument, referring to Table 2, both problem solving elements and problem solving assets were taken into consideration. In CPBL, problem solving elements consists of problem solving process, reflection and self-directed learning. In general, engineering problem solving process can be divided into three main foundational phases, which are problem identification, problem analysis and synthesis, and solution generation. Reflection and self-directed learning are two very important components in CPBL cycles, which are elements that directly enhanced problem solving skills among students that undergo CPBL. [11] Therefore, the instrument is designed based on five constructs: problem identification, problem analysis and synthesis, solution generation, self directed learning, and reflection.

Each construct of the instrument was further divided into three problem solving assets: knowledge, perception, and cognitive process, as shown in Table 2.[14, 39] Knowledge consists of concepts, facts, procedures, methods or strategies that is known which can be used to solve problems. When a person solves a problem, he will use concepts and facts to represent the problem. During planning, monitoring and implementation, a problem solver thinks whether his decision is correct, align actions with the need of the problem, and solve it.[39] Perception is the degree of confidence of a problem solver towards his ability and interest in solving a problem, or other probable factors that might improve or reduce someone's interest towards solving a problem.[39] Cognitive processing is the thinking process while engaging in productive problem solving. It involves building a cognitive model of the problem space and judging about the appropriateness of a particular plan.[14] All these problem solving assets are very important factors that highly affect the quality of a solution to a problem. It is highly interrelated to one another. In this work, all the three assets are considered in all phases of engineering problem solving process, as well as reflection and self directed learning.

To craft the statements in the instrument for each of the three problem solving asset in each of the five constructs, the process and significance of the constructs in the CPBL framework must be taken into account. The CPBL model integrates Cooperative Learning (CL) into the Problem-Based Learning (PBL). Although PBL has constructivist underpinnings, incorporating CL into PBL to become CPBL includes social constructionist principles into the model.[40, 41] The model emphasizes participation of students working together in their team as well as in the learning community developed based on CL principles.[9] The following paragraphs discuss briefly this CPBL model with respect to the five constructs:

1. **Problem identification**. A group of students (team) brainstorm their understanding about the problem. The team reach a consensus on the problem statement. At this stage, they also identify appropriate existing knowledge (what we know), additional data or information needed (what we need to know) and the learning issues (new knowledge) that must be tackled through self-directed learning. Once the problem has been specified, self-directed learning will take place among team members. Students report their discovery from research to their own teams. Team-based peer teaching can then be held. Nevertheless, students may need to reflect back, redefine the problem, or fine-tune their understanding of the problem, once they have more information and knowledge.

2. **Problem analysis and synthesis**. Information is shared and critically reviewed so that the relevant ones can be synthesized and applied to solve the problem. Facilitators at this phase ensure that the coverage of the problem is sufficient, and probes students on accuracy and validity of the information obtained. This can be an iterative process, where students may need to re-evaluate the analysis of the problem, pursue further learning, researching, reporting and peer- teaching.

3. **Solution generation**. The problem may be presented in the form of a report and an oral presentation to the class, or in other forms of deliverables, followed by more probing questions by the facilitator to ensure deeper learning. Students are asked to reflect on the content as well as the process.

4. **Reflection**: Each student is required to submit a learning and reflection journal. The engineering problem solving diagram as shown in Figure 1 illustrated that at almost every phases there are re-evaluations of the processes. This iterative nature is one of the key characteristics of engineering problem solving because engineers reflect upon their decisions, in which they will re-examine their decision and internalize them.[38] From this, new ideas might emerge. This is where critical thinking enhanced in the problem solving activities.[43, 44] In CPBL, reflections are assigned individually or team-based to the students. In submitting individual reflections and the team feedback, students develop meta-cognitive skills, which are essential for life-long learning.

5. **Self-directed learning**: Students will be conscious throughout the process of solving problem. In CPBL students are instructed to make notes in the form of explanations of what is understood, ideas or concepts that needs to be verified and questions on hazy points on the learning issues. They learn to construct new knowledge by extracting important concepts and information, explaining what they understand, and inquiring about what do not fully understand. This directly developed their self-directed learning skills.

In designing the overall structure of the instrument, the degree of maturity was chosen as the scale to determine if there is a shift from surface learning to deep learning among students before and after CPBL, as shown in Table 3, under the category of problem solving skills. The instrument follows the structure of Woods' My Role Is Questionnaire (MRIQ) to provide a contrast as well as continuity between deep and surface learning approaches. The surface and deep options are in line with Piaget's assimilation-accommodation and Chi's experts-novices. There are two main options, where Option 1 represented statements for surface learning and Option 2 represented statements for deep learning, as illustrated in the sample given in Table 3. Option 1 is for considering surface thinking while Option 2 is for deep thinking. Table 3 shows an example of how the Problem Identification construct was designed, which consists of all the elements mentioned earlier. The statements in the instrument are written in the style of a survey form. The rest of the constructs used the same format in the development. Instructions given on the front page of the form, shown in appendix A, explains the way to respond to the questionnaire. A 6-point Likert scale (from 0 to 5) is used in the instrument for analysis, ranging from "not at all true of me" (0) to "very true of me" (5). For each of the statement, the total for the two options must add up to 5. Thus, the total achieved for option 1 and option 2 will signify the degree of surface approach and deep approach respectively.

Table 3: Problem Identification Constructs Development

	Statement	Option 1 (Surface Thinker)	Option 2 (Deep Thinker)
Knowledge	When I encounter a new problem	I look for similar problems and examples in books, or notes from seniors.	I try to understand and analyze the problem relating to scientific and engineering concepts.
Belief-Motivation-Expectation	I faced a new problem,	because of marks for my grade	with interest to develop myself
	Given a choice,	I will avoid challenging problems	I prefer challenging problems
Process	When attempting to solve a new problem,	I will seek help from my friends to explain the meaning of the problem	I will try to understand the problem by redefining it using my own words
		I will immediately attempt to find the solution to the problem	I will underline the important words, list down facts and knowledge that I know, and identify concept/s that I need to learn.
	When a conflict arise during problem identification such as disagreement on certain things	I will accept my friends' point of view to avoid prolong the discussion	I will keep thinking about the matter, discuss with my friends and lecturer until I am satisfied.

Technical Characteristics

Evidence regarding the scale's psychometric properties was examined. Specifically, scores based on students data (N = 150) indicated that subscale internal consistency reliability for problem identification, problem analysis and synthesis, solution generation, reflection and self-directed learning (Cronbach's coefficient alpha) estimates were .82, .75, .80, .62 and .94, respectively, and for the total scale was .94. The instrument had been validated by experts in problem solving and cooperative problem-based learning.

Sample Study

To illustrate the use of the EPSI, the instrument was used to study the effect of undergoing CPBL after one semester on students in the Process Control and Dynamics course at the Universiti Teknologi Malaysia. This is part of a larger study on the impact of CPBL on student learning. The instructor of the course is one of the co-author of this paper. Nevertheless, she was not involved in research activities that involve direct contact with the students other than as a facilitator and instructor of the course. The main author is the main researcher who distributed the questionnaire and came into direct contact with students to obtain data for the research. He was not involved in any form of facilitation, instruction or assessment of the course.

Process Control and Dynamics is a three credit course for third year chemical engineering undergraduates. The subject dealt with mathematical modeling of process dynamic, and control systems design and analysis of chemical processes. When traditional lectures were used, the course was notorious for high number of failures (usually around 30%-45%), low passing grades (mostly in range of Cs) and challenging content. Since 2002, CL, PBL and later CPBL were gradually introduced into the course. Earlier forms of CPBL were introduced into the course gradually involving at least three lecturers in three sections and around 120 students (40 students per section) at a time. With the introduction of CPBL, the percentage of students failing the course is now less than 10%, while the average of final grade has consistently been at least a B. The current form of the CPBL framework had evolved from improvements in the model made over the years since the first implementation. The current CPBL framework was first implemented in one of the three sections of the process control course offered during the second semester of the 2009/2010 session. A detailed research was done on its outcomes to determine the actual impact of implementing CPBL in the section. This research is currently being expanded to a larger sample involving 110 chemical engineering students taking process control in the second semester of the 2010/2011 session.

The research sub-questions are:

1. Do students become better problem-solvers?
2. Do students improve their ability to identify deficiencies in learning and problem solving that they need through reflecting the process that they went through?
3. Do students become better self-directed learners?
4. Do students become better problem solvers in terms of their knowledge, expectation and cognitive processes?

The Engineering Problem Solving Skills Analysis

The first three sub-questions were answered by examining the result of the EPSI: (1) do students become better problem solvers, (2) to what extent do students improve their ability to identify deficiencies that they need through reflecting the learning process that they went through, and (3) do students become better self-directed learners.

For the first three sub-questions, the engineering problem solving processes are considered. The processes are problem identification, problem analysis and synthesis, solution generation, reflection and self-directed learning. Figure 3 shows the students' deep thinking scores at all levels of problem solving processes at the beginning and the end of the semester. When tested for normality, the data was found to be normal with a skewness and kurtosis ratios between +2 and -2. As shown in Table 4, the paired sample t-test illustrated that there are significant differences between the beginning and the end of the semester of all the means in deep thinking of the important elements of problem solving skills based on a 95% confidence level ($p<0.05$). As shown in Table 5, the effect sizes (d) for all the comparison were also greater than 0.8. According to Cohen, effect sizes greater than 0.8 have great effect in the study.[44] This means that the CPBL approach have great impact on the students' problem solving skills. The result also indicates that the students' deep thinking had improved. The statistical analysis proved that, after going through CPBL process for one semester,

1. students do become better problem-solvers,
2. students do improve their ability to identify deficiencies in learning and PS that they need through reflecting the process that they went through, and
3. students do become better self-directed learners.

The Engineering Problem Solving Assets

The next sub-question is: do students become better problem solvers in terms of their knowledge, belief/motivation/expectation and cognitive process?

Figure 4 shows students' deep thinking scores in terms of their problem solving assets at the beginning and at the end of the semester. Normality test on the data showed that all skewness ratios and kurtosis ratio are within +2 and -2. This shows that all data are normally distributed, and thus, they can be analyzed using parametric analysis. As shown in Table 6 and Table 7, the paired sample t-test illustrated that there are significance difference of all the means in deep thinking of students' knowledge, expectation and process, at the beginning compared to at the end of the semester for CPBL class. The results show that the mean values for students' deep learning are significantly higher at the end of the semester compared to at the beginning of the semester for knowledge, belief/motivation/expectation and process. As shown in Table 7, the effect sizes, d, for all the comparison are also greater than 0.8. This means that the CPBL approach in learning does have greater impact on the students' problem solving assets. This statistically proved that, after going through CPBL process for one semester, students do enhanced their problem solving assets to become better problem solvers.

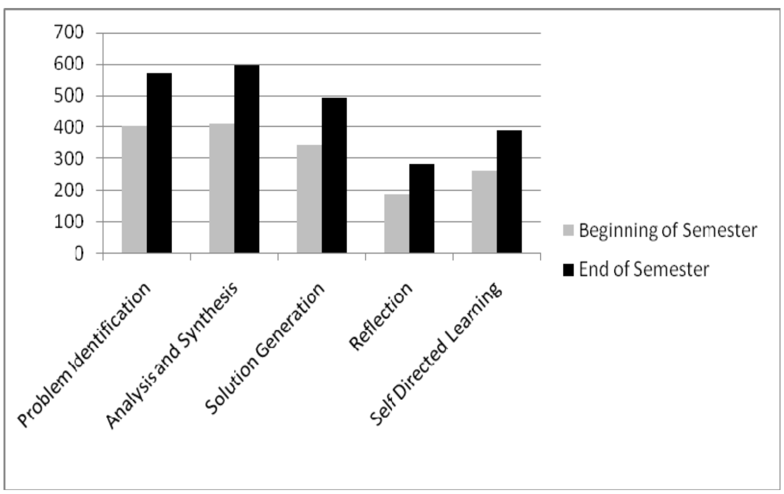


Figure 3: Deep Thinking of Engineeering PS Elements

Table 4: Paired Sample t-test for Engineering PS Elements

		Paired Differences				t	df	Sig. (2-tailed)
		Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1	Problem Identification: Beginning of Semester - End of Semester	3.441	.628	4.282	6.852	8.86	29	.000
Pair 2	Analysis and Synthesis: Beginning of Semester - End of Semester	3.859	.705	4.826	7.708	8.89	29	.000
Pair 3	Solution Generation: Beginning of Semester - End of Semester	2.828	.516	3.944	6.056	9.68	29	.000
Pair 4	Reflection: Beginning of Semester - End of Semester	1.750	.319	2.547	3.853	10.02	29	.000
Pair 5	Self-directed Learning: Beginning of Semester - End of Semester	3.126	.571	3.066	5.401	7.42	29	.000

Table 5: Paired Sample Test Result and its Effect for Engineering PS Elements

	Paired Differences			t	p< .05	Effect Size
	Mean	Std. Deviation	Std. Error Mean			
Problem Identification	5.57	3.44	.63	8.86	Sig	1.80
Analysis and Synthesis	6.27	3.86	.71	8.89	Sig	2.09
Solution Generation	5.00	2.83	.52	9.68	Sig	1.84
Reflection	3.20	1.75	.32	10.02	Sig	1.59
Self-directed Learning	4.23	3.13	.57	7.42	Sig	1.74

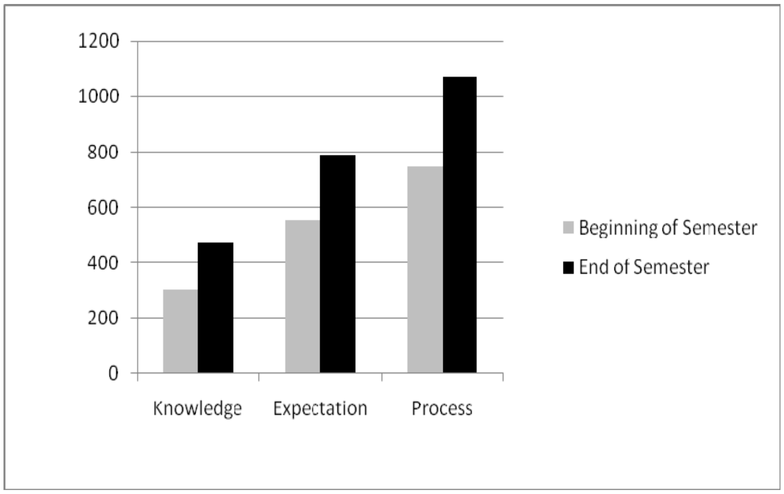


Figure 4: Deep Thinking of Engineering Problem Solving Assets

Table 6: Paired Sample Test on Engineering Problem Solving Assets

		Paired Differences					**t**	**df**	**Sig. (2-tailed)**
		Mean	**Std. Deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**				
					Lower	**Upper**			
Pair 1	Knowledge – Beginning of Semester - End of Semester	5.57	2.674	.488	4.568	6.565	11.402	29	.000
Pair 2	Expectation – Beginning of Semester - End of Semester	7.87	5.002	.913	5.999	9.734	8.615	29	.000
Pair 3	Process – Beginning of Semester - End of Semester	10.83	5.995	1.094	8.595	13.072	9.898	29	.000

Table 6 shows increased in the scores of deep thinking, as extracted from the EPSI survey. From the table, the knowledge element has the highest percentage increased in deep thinking. Figure 4 shows that students' deep thinking improved more especially the students' knowledge after undergoing CPBL. This is also explained through comparing mean values of statistical data using paired sample t-test as shown in Table 7.

Table 7: Paired Sample Test and Effect Size on Engineering Problem Solving Assets

	Paired Differences			t	p< .05	Effect Size (d)
	Mean	Std. Deviation	Std. Error Mean			
Knowledge	5.57	2.674	.488	11.402	Sig	1.92
Expectation	7.87	5.002	.913	8.615	Sig	1.76
Process	10.83	5.995	1.094	9.898	Sig	2.08

Conclusion

Since suitable quantitative instrument to study the enhancement of problem solving skills for CPBL is virtually not available, the development of the instrument is presented here. Considered the most complex of all intellectual functions, problem solving has been defined as higher-order cognitive process that requires certain pedagogical ways to improve. As a hybrid of constructivism and social constructivist approaches, CPBL is said to enhance the skills, but there are not enough evidences to justify the claimed. With the aid of the instrument, the result shows that the CPBL model does enhanced the problem solving skills by improving the students' deep learning.

Future Work

This study is part of a rigorous research on CPBL, which focused on the methodology of enhancing problem solving skills among engineering students. It is the objective of the researchers to find the answers on how the CPBL model developed problem solving skills in students, which will be addressed later though qualitative analysis.

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Appendix 1

Engineering Problem Solving Instrument (ESPI)

The following 24 items have two options (Option 1 and Option 2). Each option represents a preference you may or may not hold.

a. **SINCERELY** rate your preferences for each item by giving a score from 0 to 5.
b. **“0” means you strongly disagree** and strongly agree with the other option.
c. **“5” means you strongly agree** and strongly disagree with the other option.
d. The scores/ratings **MUST ADD UP** to 5.
e. Place your rating in box ‘$\mathbf{R_1}$’ and ‘$\mathbf{R_2}$’ next to the related option.
f. ‘R_1’ and ‘R_2’ must be **WHOLE** numbers, i.e. not fractions or decimals.

Example:

	STATEMENT	Option 1	R_1	Option 2	R_2
	When I study	I relate ideas to problems	2	I relate ideas to facts	3

R_1 plus R_2 **MUST be equal to 5**, i.e. 2 + 3 = **5;**

There is no time limitation for the questionnaire. However, try not to spend too much time on any one item. Your first reaction to the question will usually be the most accurate. Please answer **ALL** questions.