Methods to Study Enhancement of Problem Solving Skills in Engineering Students through Cooperative Problem-Based Learning

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Abstract

This paper explains methods used in determining enhancement of problem solving skills in engineering students undergoing Cooperative Problem-Based Learning (CPBL). CPBL is a hybrid of Cooperative Learning (CL) and Problem-based Learning (PBL). The CPBL cycles and engineering problem solving cycles were monitored through four stages of developments: build, bridge, extend, and expert. This transformation of learning maturity, from novice to expert, is examined using both, quantitative and qualitative methodologies. The methods of analyzing the process of enhancing the skills are explained. The pre and post-tests used several known quantitative instruments such as the MRIQ, MSLQ, and TWS to gauge the elements that enhance problem solving skills, such as students' motivation and team working skills. Since suitable quantitative instrument to study engineering problem solving skills is not available, the development of the instrument is highlighted. The process of enhancing problem solving skills is examined qualitatively using discourse analysis, interviews and reviews of students' reflection journals. The categorization and analysis are done by mapping Piaget's definition of novice versus expert for cognitive activities, with SOLO taxonomy of learning for cognitive level. This is then mapped with problem solving cycles using the House of Quality (HOQ) approach for quantification. The scope of this paper is restricted to describing the methods in determining the enhancement of problem solving skills in students undergoing CPBL.

Keywords: engineering education, problem solving skills, cooperative learning (CL), problem-based learning (PBL), cooperative problem-based learning (CPBL), novice versus expert

1.0 Introduction

Engineering schools must take into account that in the future, students will learn in a completely different way. Until today most of our engineering schools have developed curricula by predicting the problems we expect to face. In doing so, the focus is more on knowledge rather than skills. Curricula based on specific knowledge are built from the bottom up. Engineers whose education is built from the bottom up cannot comprehend and address big problems (Bransford, 2004). The central point of education is to teach people to think, to use their rational powers, to become better problem solvers. The future engineering curricula should be built around developing skills and not around teaching available knowledge. Engineering educators must teach methods and not solutions. The focus must be on shaping analytic skills, design skills and problem-solving skills.

Cooperative Learning (CL) and Problem-based Learning (PBL) are common methodologies used in response to the challenges posed by today's educational outcomes. In CL, students work together in a small group to accomplish a shared learning goal and to maximize learning (Johnson, Johnson and Smith, 2006). In PBL, besides promoting the construction of knowledge, it also contributes to the development of skills and attitudes deemed important for engineering practice (Duderstadt, 2008). Today's students are active learners. They construct their own knowledge structures and learning environments through interaction and collaboration.

To analyze the process of enhancing the skills, the pre and post-tests used several known quantitative instruments to gauge the elements of enhancing problem solving skills, which are students' motivation and team working. Since instrument to gauge engineering problem solving skills is virtually not available, this paper describe the development. It will highlighted how it is used to gauge the enhancement of the problem solving skills among engineering students in a hybrid of CL and PBL, called Cooperative Problem-Based Learning (CPBL) environment. The process of enhancing problem solving skills is examined using test papers, case study reports, reflection journals, interviews and discourse analysis. The categorization in the discourse analysis is done by mapping the Piaget's definition of novice versus expert for cognitive activities, with SOLO taxonomy of learning for cognitive level.

2. The Essentials Related to this Study

This section contains brief descriptions of some of the important concepts applied in the study. It is then followed by background of the study.

2.1 The Cooperative Problem-Based Learning Cycle

Figure 1 shows a complete cycle of a typical CPBL process implemented. The CPBL process can be divided into 3 main phases. Phase 1 consists of meeting the problem, problem identification and analysis. In Phase 2, students do self-directed learning, peer teaching, reporting, synthesis and application. At this stage facilitator must 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, reporting and peer teaching. Upon solving the problem, the students enter the Third Phase, where they do solution presentation and reflection. There is also an overall discussion on material and skills learned from the case study. For detailed discussion of the CPBL model, please refer to Khariyah and Helmi, 2010.

2.2 The Problem Solving Cycle

In general, there are three steps associated with engineering problem solving processes, the problem definition, the problem analysis and synthesis, and the solution generation (Philips, 2008).

At the problem definition step, team performs an assessment of the problem, review related criteria and constraints, and develop a plan for finding the solution. At the problem analysis and synthesis step, team members apply the information gathering from the problem definition to the problem though generation of multiple solutions by the collection, testing, analysis, and synthesis of data based on the specific problem and related constraints.

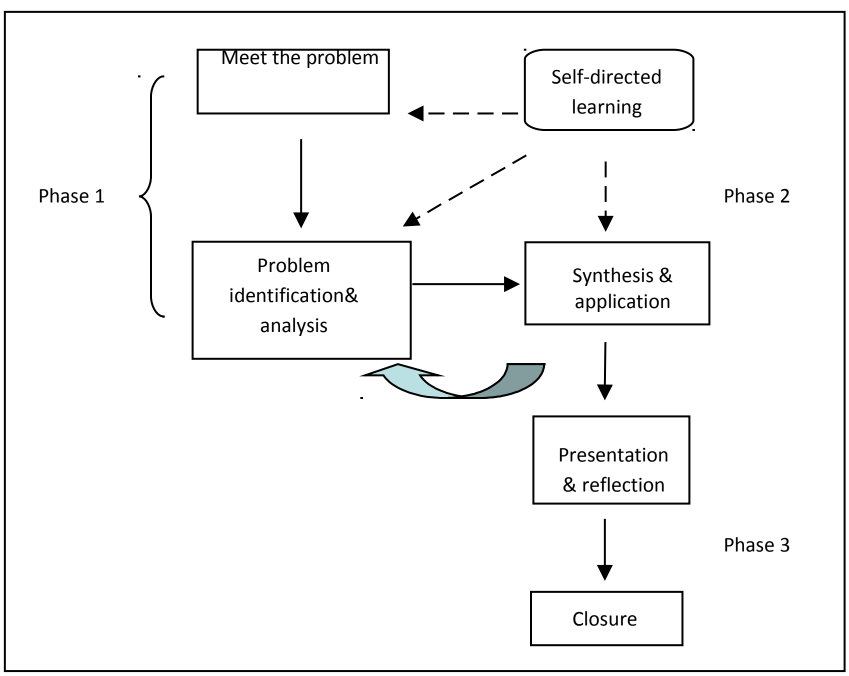

Figure 1. The Cooperative Problem-Based Learning Cycle

At the solution generation step, the team interprets the results of the testing, analysis, and synthesis, to select, recommend and present a solution to the problem. Figure 2 below presents the three foundational steps commonly used in engineering problem solving processes.

2.3 From Novice to Expert Problem Solver

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. The experts use a "working forward" method, while the novices use a "working backward" method (Breslow, 2001). The novices are considered as surface thinkers, while the experts are deep thinkers (Woods, 2000). In this study the Piaget's constructive learning theory is used to differentiate the differences among the cognitive activities of the learners, from novice thinkers to experts'.

2.4 Background of the Study

This paper explains methods used in determining the enhancements of problem solving skills among engineering students, which will be used in a research to provide evidence that CPBL does enhance the skills. In this study, data are analyzed using quantitative and qualitative methodologies. Both, direct and indirect assessments to gauge the students' problem solving skills and its' related factors are used.

For the quantitative analysis, important factors that influenced students' problem solving skills such as team working skills, students' motivation are observed, apart from the skills itself. Students' case study reports are also analyzed. For the qualitative method, problem solving skills are examined using discourse analysis, reflection journals, interviews, and reviews of students' test answer scripts. 3 teams of students' problem solving skills, which consist of 10 students, are analyzed. Table 1 and table 2 summarized the elements understudied, its' coverage and the way of assessing. Figure 3 shows timeline for the instruments used in the study.

The subject of the study consists of students and instructors for the process control and dynamics classes at the Universiti Teknologi Malaysia, Johor, Malaysia. Process control and dynamics is a three credit course for third year chemical engineering undergraduates. The subject deal with mathematic modeling of process dynamic, and control systems design and analysis of chemical processes. 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 (Helmi and Yusof, 2008).

A detailed research need to be done on its outcomes, practices and implementation. This paper describes the methods used in determining the enhancement of problem solving skills in students undergoing CPBL.

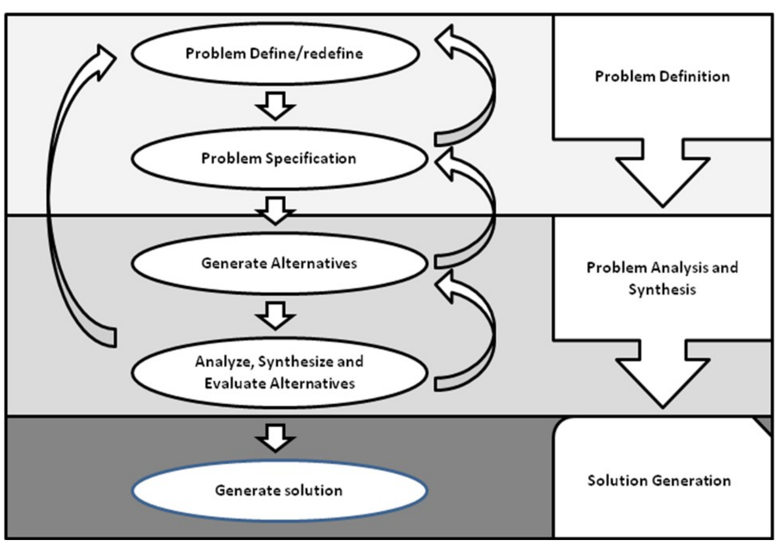

Figure 2. The Engineering Problem Solving Cycle (modified from Philips, 2008)

Table 1: Quantitative Analysis

		Coverage	Direct	Indirect
1	Problem Solving Skills	Whole Class		√
2.	Lecturers' Readiness	Lecturers Only		√
3.	Team Working Skills	Whole Class		√
4.	Students' Motivation	Whole Class		√
5.	Case Study Reports	3 groups	√	

Table 2. Qualitative Analysis

		Coverage	Direct	Indirect
1.	Teams' Discussion Discourses Analysis	3 teams	√	
2.	Students' Reflection Journals	10 students		√
3.	Students' Tests Answer Scripts	10 students	√	
4.	Researcher's Interviews	10 students 3 tutors		√ √

Figure 3. Timeline for Instruments Provided

3. Methods and Analyses to Study the Enhancement of Problem Solving Skills

Both qualitative and quantitative research methodologies are carried out to evaluate the process of enhancing problem solving skills among the students throughout the semester. Quantitative methodology is used in pre and post analysis, and across the period of the study. Quantification often makes the observations more explicit. It also can make it easier to aggregate, compare, and summarize data. Further, it opens up the possibility of statistical analysis. Quantitative data, then, have the advantages that numbers have over words as a measure of some quality. Qualitative methodology allows the researcher to fully explore the multiple variables and details the instructional practices that may facilitate the development of students' problem solving skills (Merriam, 1998; Yin, 2003). The naturalist context of qualitative methodology allows the researcher to investigate the variables in a holistic, in-depth manner, while preserving them without risk of controlling or losing the very factors that may contribute to the development of the skills (Yin, 2003). Linking qualitative data is suggested when: (a) the research is both confirmatory and exploratory in nature; (b) when quantitative data can facilitate the qualitative aspect of the study; and (c) to corroborate data by way of triangulation. This study meets all three conditions.

3.1 Quantitative Analysis

The quantitative study deal with three (3) main attributes: (1) the students' motivational level, MSLQ (Pintrich, 1990), (2) the students' team-working skills, TWS (Moore, 2006), and (3) the students' problem solving skills, PSS. The first two used known survey instruments while the third instrument is developed by the researcher.

The purpose of these instruments are to evaluate the problem solving skills outcome (or product) of the CPBL implementation, which the researcher considered as the elements necessary to enhance the problem solving skills. MRIQ is an instrument used to identify the most suitable class to conduct the study, which is based upon lecturer's readiness to facilitate CPBL (Woods, 1997).

3.2 The Designed Problem Solving Skills Quantitative Instrument

The questionnaire is designed based on five (5) constructs: Problem Identification, Problem Analysis and Synthesis, Solution Generation, Self Directed Learning, and Reflection. These constructs are selected based upon the engineering PS cycles and the CPBL cycles. For each construct, 3 main areas are considered: knowledge, belief/ motivation/expectation, and PSS processes (Adams, 2005). Table 3 shows an example of how Problem Identification construct is designed. Option 1 is for considering surface thinking (the novices) while Option 2 is for deep thinking (the experts). The rest of the constructs used the same format in the development.

In semester II - 2009/10 there are three (3) classes conducted using CPBL as mode of teaching and learning. The research operation begins by conducting a survey to identify the most prepared lecturer that implementing CPBL using MRIQ instrument. This is necessary as to propose the promising practices in conducting CPBL to enhance problem solving skills. The identified lecturer's class and his mode of facilitating are used as a case study throughout the research, in both, using quantitative and qualitative methods.

As for the quantitative analysis, at the beginning of the semester, pre-test on students' motivation (MSLQ), team-working skills (TWS) and problem solving skills (PSS) are conducted to all students taken process control subject in the selected lecturer class. The related test is given again to all students at the end of the semester (post-test) to gauge the advancement in the elements enhancing PS skills.

As for the qualitative analysis, three groups are monitored closely. The first group is the best group with respect to the result of the survey on students' motivation. The second is the intermediate and the third is the worst. All the three groups' problem-solving discourses are recorded and transcribed. Based on this, the problem solving developmental process is studied and quantified.

3.3 The Qualitative Analysis

The qualitative analyses are done using four types of data; (1) The Team Discussion Discourse Analysis, (2) the Students' Tests Answer Scripts, (3) The Students' Reflection Journals, and (4) The Researcher's Interviews. Discourse analysis is a way of approaching and thinking about a problem (Frohmann, 1994). Team-based protocol is used in the discourse analysis. Team-based protocol is used to eliminate the deficiencies caused by placebo effect (Rosenthal, 1963) and Hawthorne effect (Adair, 84).

Table 3: Problem Identification Constructs Development

	Statement	**Option 1**	**Option 2**
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/Ex pectation	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.

Data are captured using voice recording method. This method is commonly accepted since it is easy to conduct, easy to playback, minimum Hawthorne effect, and less costly (Xu and Rajlich, 2005). After the data is captured, it is transcribed into "raw protocol". The raw protocol is then divided into small units called "segments" or "episodes". The episodes are classified based on concepts that the dialog deal with. Table 4 shows the proposed classification.

There are a total of 10 students in the 3 selected groups. All the 10 students' tests and exam papers are critically reviewed and studied to see patterns of enhancement in the students' higher order thinking, thus, their problem solving skills (Woods, 2000). Their reflection journals and meta-refection journals are also reviewed to see the ways they enhanced the skills. All the 10 students plus 3 tutors (who were ex-students of the CPBL control class and who involved in designing of the case-studies given) are also interviewed. The results of the interviewed are critically studied.

3.4 The Analysis and Quantification Process

As for the discourse analysis, after the data is transcribed and divided into episodes, data analysis is conducted. In the analysis, the combination of the famous constructive learning theory (Piaget, 1954), and the SOLO taxonomy of the cognitive domain (Biggs and Tang, 2007) are used. Constructivist learning theory is used to define the differences among the cognitive activities, and the SOLO taxonomy is used to classify the cognitive levels. Table 5 and Table 6 show the four cognitive activities of Piaget's and SOLO's. Table 7 and 8 show matrixes used for analysis and quantification purposes. Table 8 is a modification of Xu and Rajlich (2005). Instead of using SOLO's, Xu and Rajlich used BLOOM's Taxonomy as a measure of cognitive levels. The results of the matrixes are analyzed using House of Quality concept (Cohen, (1995), and Hauser and Clausing (1988)).

4. Future Work

All the quantitative and qualitative data required in the analysis are gathered. They will be used to analyze two main areas; (1) the important elements that are required to enhance students problem solving skills which are team working, students motivation and self directed learning, and (2) the process of enhancing engineering problem solving skills, and the practices in the process that enhanced the skills. The result of the study can justified the claim by PBL practitioners that the teaching methodology does enhanced students' problem solving skills. It will also be used as a guideline for those who are going to apply CPBL in their teaching.

Table 4. Problem Solving Phases, Steps and Proposed Discourse Interaction
(Modified from Phillips, 2008)

Problem Solving Phases	Processes	Descriptions of Discourse Interactions	Proposed of Discourse Interactions
Problem Definition	Identify the problem	Limited series of short, introductory interactions	To orient team members to the problem and constraints
	Identify criteria and constraints of the problem	Interactions increase in complexity as collaboration increases.	To form a team consensus or plan with division of tasks
Problem Analysis and Synthesis	Generate alternative solutions	Continue increase in interactions for forming alternatives	To pool or share knowledge; to discuss alternatives
	Analyze, synthesize, and evaluate solutions	Slight decrease in interactions as data is analyze, synthesize, and interpreted; shift to	To evaluate testing data and recommend a solution

		question and answer statements	
Solution Generation	Recommend final solution	Continue decrease in interactions; shift to declarative statements	To assess task required to complete the problem.

Table 5. The Four Cognitive Levels of SOLO's (Biggs and Tang, 2007)

Cognitive Level	**Verbs**
Extended Abstract	Theorize, hypothesize, generalize, reflect, generate, create, compose, invent, originate, prove from principles, make an original case, solve from principles
Relational	Apply, integrate, analyze, explain, predict, conclude, summarize, review, argue, transfer, make a plan, characterize, compare, contrast, differentiate, organize, debate, make a case, construct, review and rewrite, examine, translate, paraphrase, solve a problem
Multistructural	Classify, describe, list, report, discuss, illustrate, select, narrate, compute, sequence, outline, separate
Unistructural	Memorize, identify, recognize, count, define, draw, find, label, match, name, quote, recall, recite, order, tell, write, imitate
Prestructural	Missed point

Table 6. The Four Cognitive Activities of Piaget's (Xu and Rajlich, 2005)

Cognitive Activities	**Sample Verbs**
Absorption	Add, believe, choose, conclude, confirm, consider, create, define, demonstrate, determine, identify, image, imply, interpret, make out, prove, reorganize, set up, show, start, think, verify, visualize
Denial	Decline, disapprove, refuse, reject, turn down
Reorganization	Adjust, alter, break, change, extract, fix, modify, move, pull out, re-factor, regroup, tune up
Expulsion	Delete, dismiss, eliminate, erase, exclude, expel, force out, get rid of, kill, remove, take out, throw away, withdraw

Table 7. Solo Taxonomy vs. Piaget's Definition

Piaget Definition	Assimilation		Accommodation	
Cognitive Activities / Solo Taxonomy	Absorption	Denial	Reorganization	Expulsion
Extended Abstract				
Relational				
Multistructural				
Unistructural				
Prestructural				

Table 8. Problem Solving vs. Solo Taxonomy Matrix

PS Skills / Cognitive Activities	Problem Definition	Problem Analysis and Synthesis	Solution Generation	Self Directed Learning	Reflection
Absorption	Novice PS				
Denial					

Reorganization	Expert PS				
Expulsion					

5. Conclusion

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 social constructivist approaches, CL and PBL are said to enhance the skills, but there are not enough evidences to justify the claimed. This paper explains a rigorous study on CPBL, which focused on methods of enhancing PS skills. It is the objective of the researchers to find the answers to the following problems; (1) Does CPBL model enhanced problem solving skills among engineering students? (2) How the CPBL model developed problem solving skills in students? And, (3) what are the practices in the CPBL process that enhance problem solving skills?

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