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Enhancement of Team-based Problem Solving Skills in Engineering Students through Cooperative Problem-based Learning*

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This paper presents a study of the enhancement of team-based problem solving skills among engineering students who undergo Cooperative Problem-Based Learning (CPBL) in an engineering course. The design of the CPBL framework aims to promote team-based learning and enhance problem solving skills. The CPBL cycle and engineering problem solving cycle entail four stages of development: build, bridge, extend, and apply. The study examines this transformation of learning maturity, from novice to expert, using quantitative methodology. Based on pre and post-tests, utilizing quantitative instruments, which are the Engineering Problem Solving Instrument and Team-Working Effectiveness Score, the results show that students significantly enhanced their team-based problem solving skills.

Keywords: engineering education; team working; problem solving skills; cooperative learning (CL); problem-based learning (PBL); cooperative problem-based learning (CPBL)

1. Introduction

The engineers of our world, in the 21st century and beyond, face great challenges. Environmental issues, aging infrastructure, and many other dilemmas have been classified under the grand challenges of the 21st century [1, 2]. Moreover, the students of engineering will need to face new engineering frontiers, categorized as 'tiny systems' and 'macro systems' [3]. Tiny systems are those associated with nano-technology where things get ever smaller, faster, and more complex. Macro systems are those that greatly affect society at a larger scale, such as energy, water, environment, communication, and logistics. Much of the work of our future engineers will be to move tiny systems technology into macro systems application [3].

"The Engineers 2020" report [4] offers a glimpse of what engineers need to be able to do in the coming years. The report states, "In the new century, the parties that engineering ties together will increasingly involve interdisciplinary teams, globally diverse team members, public officials, and a global customer base". Significant characteristics that will support the success of the engineering profession in 2020 and beyond that have been listed in the report include: (i) possessing strong analytical skills, (ii) exhibiting practical ingenuity, (iii) creative, (iv) good communication skills, (v) mastering the principles of business and management, (vi) understanding the principles of leadership, (vii) high ethical standards, (viii) professionalism, (ix) dynamic, agile, resilient, flexible, and (x) lifelong learning. The first three and the last three concern problem solving; the fourth, sixth and seventh are related to team working.

Engineering schools must take into account that in the future, students will need to 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 has been more on knowledge rather than skills. Curricula based on specific knowledge are built in silos from the bottom-up. Engineers whose education is built from the bottom up cannot comprehend and address big problems [5]. As stated by Gagné that "the central point of education is to teach people to think, to use their rational powers, to become better problem solvers" [6]. According to Katehi [7], the future engineering curriculum should be built around developing certain skills and not around merely absorbing available knowledge. Engineering educators must teach methods and not solutions, and focus on shaping analytical skills, design skills and problem-solving skills.

Cooperative Learning (CL) and Problem-based Learning (PBL) are possible approaches that can meet these requirements. In CL, students work together in a small group to accomplish a shared learning goal and maximize learning [8]. PBL, besides promoting the construction of knowledge, develops skills and attitudes important for engineering practice [2]. Students become active learners who construct their own knowledge structures and learning environments through interaction and col-

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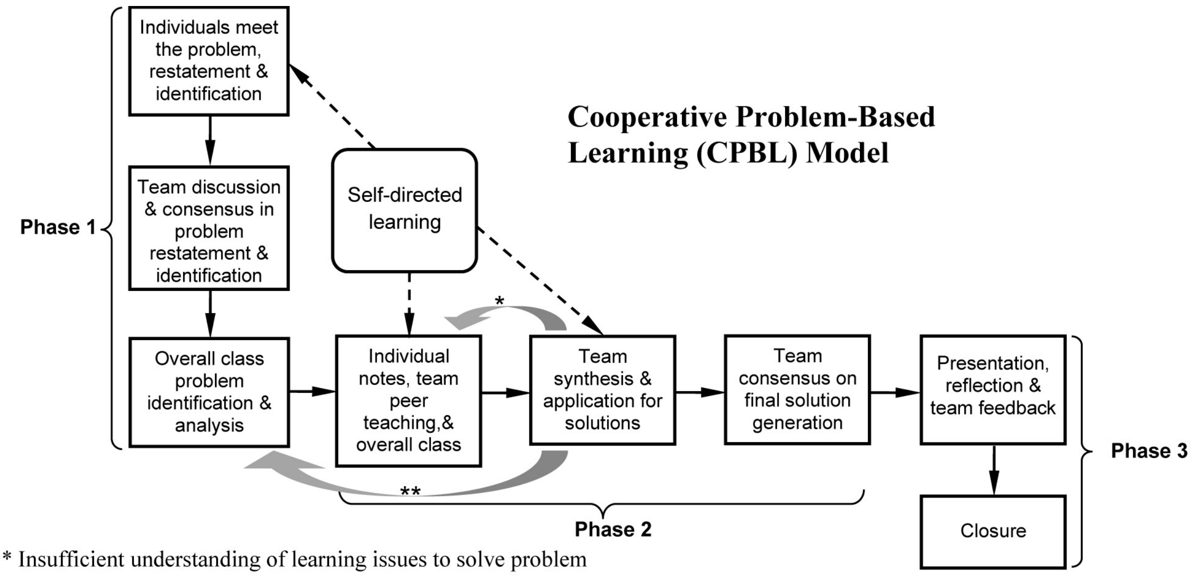

* Insufficient understanding of learning issues to solve problem
**Incomplete understanding or misunderstanding of problem requirements

Fig. 1. The Cooperative Problem-based Learning Cycle [10].

laboration. Integrating these two forms of learning, Cooperative Problem-Based Learning (CPBL) was introduced to enhance students' skills, especially team-based problem solving. This paper presents a study among engineering students on the impact of undergoing CPBL in a course for one semester on team-based problem solving skills.

1.1 Cooperative Problem-based Learning (CPBL)

CPBL is the infusion of Cooperative Learning (CL) principles into the Problem-Based Learning (PBL) cycle to provide crucial support for students through the development of team-based learning skills in a typical course setting [9]. Fig. 1 shows a complete cycle of a CPBL process.

The CPBL process is divided into 3 phases, as shown in Fig. 1. Phase 1 consists of meeting the problem, problem identification and analysis. Students are facilitated to understand the problem and identify missing information and gaps in the knowledge required to solve the problem. Phase 2 consists of self-directed learning, peer teaching, reporting, synthesis and application. At this stage, the facilitator must ensure that the depth of knowledge learned is sufficient, and probe students on accuracy and validity of the information obtained. Phase 1 and Phase 2 can be iterative, where students may need to re-evaluate the analysis of the problem, pursue further learning, reporting and peer teaching. Upon solving the problem, students enter Phase 3, where they carry out solution presentation and reflection. There is also an overall discussion on material and skills learned from the problem.

To provide explicit learning context to the students, problems designed should be realistic, or even real. They represent professional practices that resemble working environments that students may possibly encounter in actual practice. The problems require students to perform the same learning activities in the learning environment as they would in the workplace. The complexities of the problems are suitable enough to ensure participation and engagement in the learning process, promote self-directed learning and lifelong learning. Solving the problems should lead to a higher cognitive level where critical thinking and metacognition are developed.

In one semester, students go through four problems, which correspond to four stages of development: build, bridge, extend, and apply. In CPBL, the problems are structured and dealt with such that each problem-solving process brings students up to a higher level of expectation. The learning environment that students go through in solving four problems through a series of CPBL cycles is designed to support students to move from being novice engineering problem solvers towards developing expertise. This occurs within the course duration of one semester of about 14 weeks. This idea of organizing problems in one semester is shown schematically in Fig. 2. Detailed discussions on CPBL and crafting problems for engineering courses can be seen in a number of studies [10–13].

2. Research questions

The aim of this study is to determine if the CPBL model enhances team-based problem solving skills among engineering students. There are five research questions, which are very much in line with those

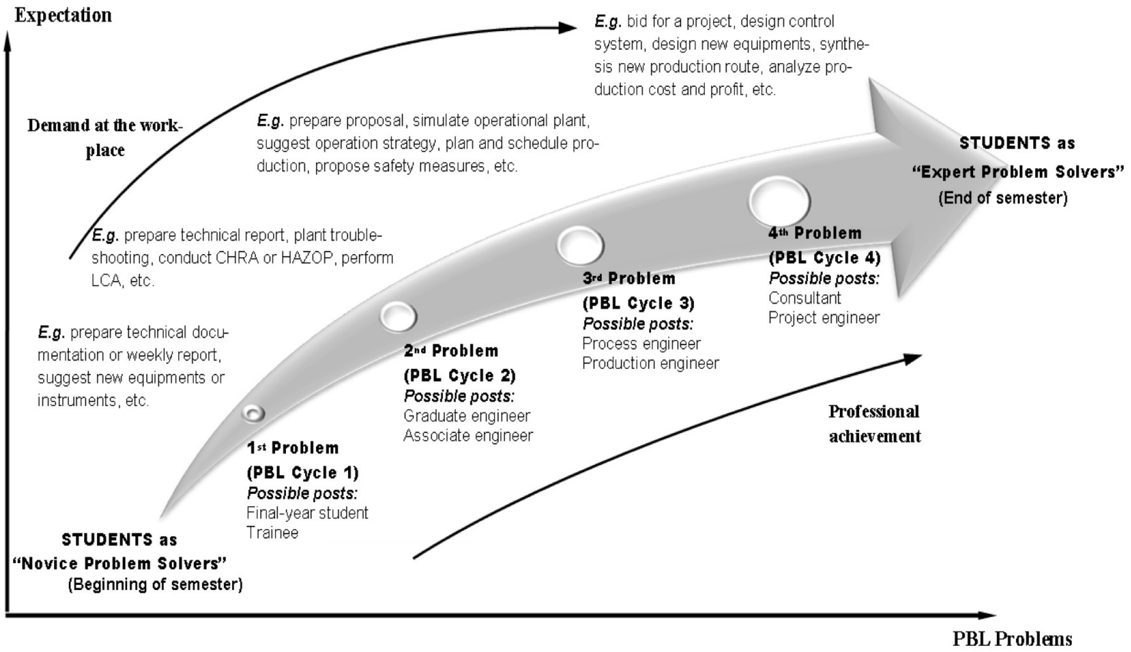

Fig. 2. Example problem scenarios in CPBL

recommended by Barrows and Kelson [14]. They are:

1. Do students become better problem-solvers through the process of CPBL?
2. Do students improve their ability to reflect upon the process they went through in solving problems?
3. Do students become better self-directed learners by engaging in solving problems?
4. Do students improve their team working skills by solving problems cooperatively in CPBL, which leads to enhancement of their team-based problem solving skills?
5. Do students become better problem solvers in terms of acquiring their problem solving assets through CPBL?

3. Literature review

This section contains brief descriptions of some of the important concepts applied in the study, which are problem solving, team-working, cooperative learning and problem-based learning. It is then followed by discussion about engineering problem solving skills instruments, and team-based assessment.

3.1 Problem solving skills enhancement in engineering education

Engineers have to be creative problem solvers [1]. Yet, today's engineering education gives greater emphasis to memorizing information and formulae. At work, professionals are not paid to memorize facts or take written examinations. Ironically, these are the primary indicators of academic achievement. Students are seldom required to solve actual work place problems in their curriculum. Problems that they often solve are inconsistent with the nature of real world problems which they are supposed to solve in their everyday lives.

A study by Jonassen [15] explained a range of outcomes of problem solving in relation to their different instructional design requirements. A well-structured problem tends to have an instructional design rooted in information-processing theory. This theory suggests that the learning outcome as skills that can be applied across certain domains. In contrast, ill-structured problems tend to be embedded in theory concerning constructivism and situated cognition. The theory regards learning outcomes as skills that have a specific domain for each performance. Thus, Jonnesen [16] recommends embedding instructions in a specific real world context. A crucial reason that learners face difficulties is their lack of understanding and experience in actual problem solving activities.

Problems can be different in their nature and component parts. Mayer and Wittrock [17] differentiate ill-defined versus well-defined problems, and routine versus non-routine problems. Similarly, Jonnesen [18] distinguishes well-structured from ill-structured problems and enunciates differences in cognitive processing used. Smith [19] distinguishes between internal and external factors in problem solving: external factors are variations in problem type and representation; internal factors are those that describe variations among problem solvers themselves.

Jonassen, Strobel and Lee [20] identify 12 attributes of workplace engineering problems. They explicate the parameters of workplace engineering problem solving, arguing that the parameters should be used to design learning experiences to better prepare students to meet the challenges of accreditation requirements under the Washington Accord, and as recommended by the "Engineer of 2020" report [5]. Jonassen et al. suggest that one solution is convert curricula into PBL [20]. However, Woods [21] warns about the 8-steps of "grieving" that students will go through when they first face PBL, steps that appear similar to the post-traumatic emotional cycle identified by psychologists. Students' motivation and attitude towards learning greatly influence the grieving process. Coping and struggling with this will help them develop resilience. Woods [22] suggests that problem solving skills are best developed through a three-stage process: (1) build; (2) bridge; and (3) extend, through PBL methodology.

3.1.1 Problem solving process

In general, the engineering problem solving process can be divided into three foundational phases: definition, strategy, and solution phases [23]. In the definition phase, problem solvers try to identify all the unknown and known information related to the problem, the scope of the problem, learning issues, constraints and limitations to the solutions. In the strategy phase, problem solvers apply the information gathered from the problem definition to the problem, applying knowledge to generate several solution alternatives by collecting, testing, analysing, and synthesising information and data based on the specific problem and related constraints. In the solution generation phase problem solvers interpret the results of the analyses and synthesis to select and recommend the solution.

Each of the phases represents a general overview of the engineering problem solving process. Effective problem solvers understand and apply each phase, which includes a series of actions. Fig. 3 shows the three phases of problem solving in relation to the traditional series of detailed procedures and actions commonly used in the engineering problem solving process. These phases of problem solving serve as critical anchors for more detailed activities required for effective solutions. A consistent feature of engineering problem solving is that of iteration. In CPBL, apart from problem solving, self-directed learning and refection are also explicitly stated [10].

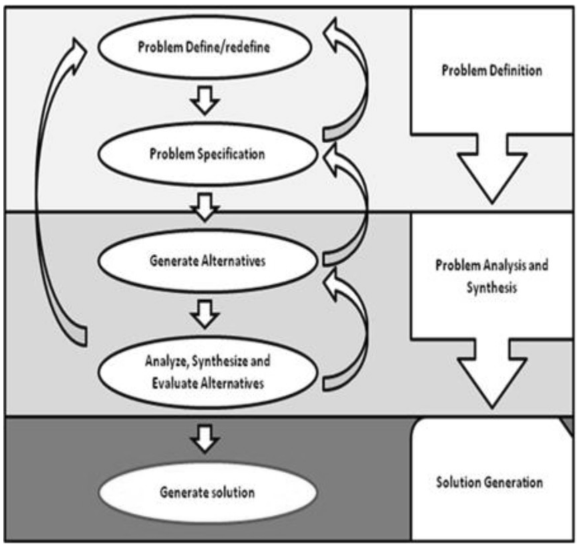

Fig. 3. The Engineering Problem Solving Process [12].

3.1.2 Problem solving assets

Researchers have identified and categorized important assets needed for problem solving. Mayer and Whitrock [17] divide assets into knowledge and cognitive processes. Mayer and Whitrock' structure of "knowledge and processes" or "knowing and doing" covers all the assets needed to solve any problem and does not imply significance of one over the other. The division clarifies metacognitive knowledge and meta-processing which are often lumped together but have different effects on problem solving. Adams [24] extracts out beliefs and expectations from knowledge and places them with motivation in an additional category. The divisions are made based on what problem solvers bring with them to the problem: (1) knowledge, (2) beliefs, expectations and motivation, and (3) processes. When formulating a mental representation, problem solvers use facts and concepts they believe apply to the problem. While planning and monitoring the progress of the plan, they use problem solving strategies. When executing the plan, they apply the procedural knowledge they have on the specific topic. Beliefs, expectations and motivation influence knowledge and processes because they shape a student's cognitive processes by mediating how and which knowledge items will be used, as well as the type and the extent of the effort put in to solve the problem.

Knowledge consists of factual, semantic, procedural and strategic knowledge. Beliefs and expectations include ideas about what students expect and what they believe is important or useful about themselves and about the problem. There are many types of motivation, evident among those who are internally, externally, weakly or negatively motivated. Cognitive processing happens when humans engage in productive problem solving [24].

3.2 *Team-working*

Teams are social entities, where individuals cooperate to achieve a common goal. Guzzo and Dickson [25] define teams as groups "made up of individuals who see themselves and who are seen by others as a social entity, who are interdependent because of the tasks they perform as members of a group, who are embedded in one or more larger social systems, and who perform tasks that affect others." Campion, Medsker and Higgs [26] define teams in terms of characteristics, claiming that a group is a team if the characteristics of job design, interdependence, composition, context, and potency are demonstrated.

Several crucial factors are required for a functional team. Locke and Latham [27] propose goal-setting and task performance theory in the field of industrial-organizational psychology which stresses the necessity of setting goals for teams to perform effectively. Scholtes [28] states team working is one of the most important attributes of an effective leader. Meanwhile, Imbrie, Maller, and Immekus [29] classify the traits of effective teams as potency, interdependency and goal setting. "Potency" is defined as having shared belief in a team so that they can be effective. "Interdependency" is defined as cooperating with each other to accomplish a task. "Goal setting" is defined as establishing goals to accomplish a given task.

3.3 *Cooperative learning and problem based learning*

In Cooperative Learning (CL), students work together in a small group to accomplish a shared learning goal and maximize learning. Johnson, Johnson and Smith [8] articulate five principles of cooperative learning: positive interdependence, individual accountability, face to face interaction, appropriate interpersonal skills, and regular assessment of team functioning. Smith and Imbrie [30] report that Johnson and Johnson [31] list seven methods used by groups to make decisions for solving problems, where consensus is the most effective. They list five characteristics of effective decisions: effective use of resources, effective use of time, making correct or high quality decisions, all members are fully committed to the decision, and enhanced team-based problem solving skills. Garvin and Roberto [32] suggest that making collective decision should be viewed as an inquiry approach rather than as an advocacy process, so that decision making is seen as collective problem solving rather than as a competition.

Problem based learning (PBL) originally emerged as a response to dissatisfaction with medical education [33]. Used in a variety of disciplines, PBL gained world-wide interest as an innovative technique to encourage deep learning and a multitude of professional skills essential for engineering graduates [34]. Although it is commonly agreed that PBL starts with a problem, there are various models, and thus various implementation techniques. The literature on PBL concerns many areas: its definition [33, 35]; history [35]; introduction [36]; summary of research [37]; meta-analysis comparing PBL to conventional classroom teaching [38]; and critiques of PBL [39].

Unstructured problems, which may be real or realistic, are used as the starting point of learning to create deep interest among students to learn together new knowledge and integrate existing understanding, forcing them to think critically and creatively to solve problems [21, 24, 40, 41]. A CPBL learning environment can accommodate all the desired skills outcomes required by professional bodies. More importantly, the strength of CPBL lies in shaping attitudes as well as creating interest and excitement in learning otherwise dry content, motivating students to cultivate interdependence in learning, thinking and problem-solving in and among teams.

4. The Conceptual framework

The conceptual framework for this study is mainly shaped by theories and empirical studies on how to prepare future engineers in an increasingly challenging world, an approach extensively reported by several authors [1–5, 42]. Other approaches that shape the conceptual framework are drawn from the literature on problem solving skills in engineering education [15, 20, 21, 23, 24]; and writings on teamwork [8, 21, 29, 30, 41, 43–45].

Fig. 4 depicts the conceptual framework. The ability to solve problems is the main skill required by a creative, innovative and practical engineer. Integrating teamwork with engineering problem solving is expected to enhance team-based problem solving skills among engineering students. This is done by infusing a series of CPBL cycles, thus enabling students to become effective problem solvers. Our study hypothesizes that the approach will contribute to the development of future engineers in their ability to solve real world problems. Three main theories underpinning the study are: (1) the characteristics of future engineers that assist in developing effective problem solvers, in terms of their cognitive, affective and professional domains;

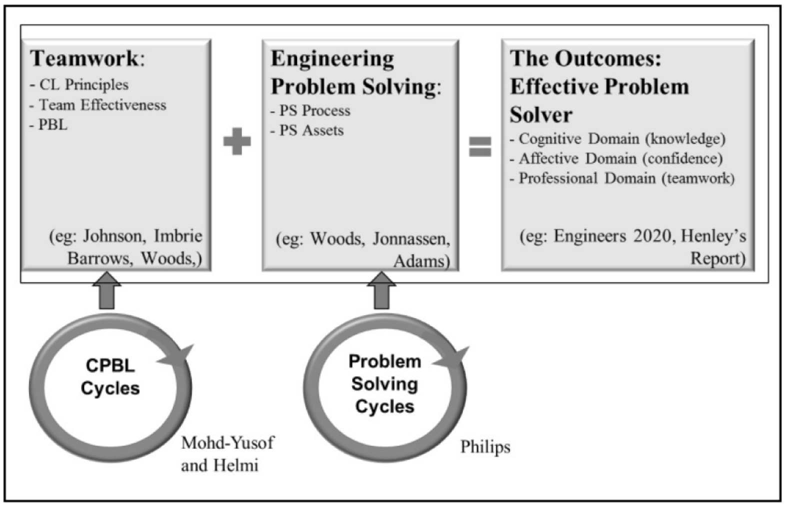

Fig. 4. Conceptual framework.

(2) the processes and assets required for engineering problem solving; and (3) team working through the integration of CL into PBL.

5. Methodology

Two survey instruments were used to measure problem solving skills and team-working skills among 35 chemical engineering students who had undergone CPBL for a semester in a third year Process Control and Dynamics course. The two instruments are Engineering Problem Solving Instrument (EPSI) and Team Working Effectiveness Score (TWES). Table 1 summarizes the elements studied, their coverage and the assessment method.

The instruments were administered twice during the semester. The pre-test was conducted in Week 3, immediately after the first problem was completed. Thirty-five third year students voluntarily answered both questionnaires. Before the students answered the questions, they were informed of the objectives of the research. The post-test was conducted just after the last problems were discussed, which was almost at the end of the semester. The instruments were answered by the same students for both pre- and post-tests.

Table 1. Summary of Quantitative Instruments

Quantitative Analysis	Constructs
EPSI [12]	i. Problem Identification ii. Problem Analysis and Synthesis iii. Solution Generation iv. Reflection v. Self-directed Learning (based upon: knowledge, confidence, and process)
TWES [29]	i. Interdependency ii. Potency iii. Goal Setting

Since the study is quasi-experimental without a control group, the generalizability of the result may be limited. To overcome this, a qualitative study was also carried out. The qualitative results ensured the internal and external validities of the study. The outcomes of the qualitative study were aligned to quantitative results, and have been reported in Helmi et al. [55].

5.1 The engineering problem solving instruments (EPSI)

The EPSI was designed based on five constructs: problem identification, problem analysis and synthesis, solution generation, self-directed learning, and reflection [12]. These constructs are based upon the engineering problem solving cycles and the CPBL cycles. For each construct, 3 main areas are considered: knowledge, confidence, and process. Confidence is an asset based on the beliefs, expectations and motivations of the problem solvers.

Evidence on the EPSI scale's psychometric properties was examined. Specifically, scores based on students' data ($N = 150$) indicated that the subscale internal consistency reliability estimates for problem identification, problem analysis and synthesis, solution generation, reflection and self-directed learning (Cronbach's coefficient alpha) were 0.82, 0.75, 0.80, 0.62 and 0.94 respectively, and 0.94 for the total scale. The instrument was validated by experts in problem solving and CPBL. A detailed description of the instrument can be found [12].

5.2 Team working effectiveness score (TWES)

The Team Working Effectiveness Score (TWES) was utilized as an instrument to assess team effectiveness in terms of interdependency, goal setting and potency [29]. Teams that demonstrate interdependency demonstrate cooperation among team members to accomplish a task [25]. Potency is the shared belief by a team that they can be effective [46]. Goal setting is the ability of a team to set goals and sub-goals to accomplish a task [27]. This framework is used to assess team effectiveness. By working cooperatively using teaming theory as a guide for skill development, students can be motivated towards the goal of problem-solving [54].

Evidence regarding the scale's psychometric properties was examined in a study by Imbrie et al. [29]. Scores based on data on freshmen students ($N = 1{,}060$) indicates that subscale internal consistency reliability for interdependency, goal setting, and potency (Cronbach's coefficient alpha) estimates were 0.96, 0.92, and 0.96, respectively, and for the total scale was 0.98. Results of a confirmatory factor analysis indicated that a one factor model fit the data: $\chi 2$ (254) = 316.15, $p = 0.005$, $\chi 2/df = 1.24$, $RMSEA = 0.02$, $CFI = 1.00$, $GFI = 1.00$. This confirms that items can be summed up to create a composite score, thus operationalizing a definition of effective teaming that was based on a measure with construct validity evidence.

5.3 Subjects of the study

The subjects of the study comprise 35 third year chemical engineering students in the Process Control and Dynamics course at a university in Malaysia. Process Control and Dynamics is a three credit course which deals with mathematical modeling of process dynamics, control systems design and analysis of chemical processes. The course was notorious for a high number of failures, low grades and challenging content. Since 2003, CPBL was introduced gradually into the course. With the introduction of CPBL, the percentage of students failing the course is less than 10% compared to 30% before the implementation, while the average final grade has consistently been at least a B [47]. Detailed research is required on the outcomes, practices and implementation of the course.

6. Results and data analysis

The data was analyzed using Statistical Package for Social Sciences (SPSS) software. The key emergent themes are presented in three sections: (i) students' problem solving elements; (ii) team working effectiveness; (iii) students' problem solving assets. The engineering problem solving elements and problem solving assets were analyzed using pair sample t-test since the data were normally distributed. However, for team working effectiveness, the Wilcoxon Signed Ranks was used since the test for normality appeared otherwise.

6.1 The engineering problem solving elements

The impact of CPBL on problem solving elements was analyzed using quantitative analysis. The Engineering Problem Solving Instrument (EPSI) was used to measure improvements in problem solving elements as perceived by engineering students upon going through a course of CPBL. The deep thinking approach before and after the students went through the course was compared.

The following three questions were answered by examining the results of the EPSI: (1) do students become better problem solvers? (2) Do students improve their ability to reflect on the process they went through in solving problems? (3) Do students become better self-directed learners by engaging in solving problems? For the first question, the engineering problem solving processes, which are problem identification, problem analysis and synthesis, and solution generation, are considered. For the second and third questions, the constructs in EPSI are reflection and self-directed learning.

Fig. 5 illustrates that students' deep thinking scores at the beginning in all levels of engineering problem solving processes, reflection and self-directed learning, are significantly lower than the scores at the end of the semester. It shows an increase in the scores of deep thinking based on students' perceptions at the beginning of the semester and at the end of the semester. Deep thinking in the form of students' reflection increased the most, followed by students' self-directed learning. The students' problem solving process increased by about 30%.

The result of the paired sample test is shown in Table 2. The mean values for deep thinking at all level of problem solving processes, reflection and self-directed learning increased at the end of the semester compared with the beginning of the semester. As shown in the table, the paired sample t-test illustrated that there are significant differences in all the means for deep thinking of the students' problem solving elements between the beginning and the end of the semester. Referring to Table 2, the t-test results are:

$t(35)_{\text{Problem Identification}} = 8.86;\ p < 0.05$
$t(35)_{\text{Problem Analysis and Synthesis}} = 8.89;\ p < 0.05$
$t(35)_{\text{Solution Generation}} = 9.68;\ p < 0.05$
$t(35)_{\text{Reflection}} = 10.02;\ p < 0.05$
$t(35)_{\text{Self-Directed Learning}} = 7.42;\ p < 0.05.$

As shown in the table, the effect sizes (d) for all the comparison are also greater than 0.8. According to Cohen [48], effect sizes greater than 0.8 have significant effect in the study.

6.2 Team working effectiveness

The impact of CPBL on team working elements

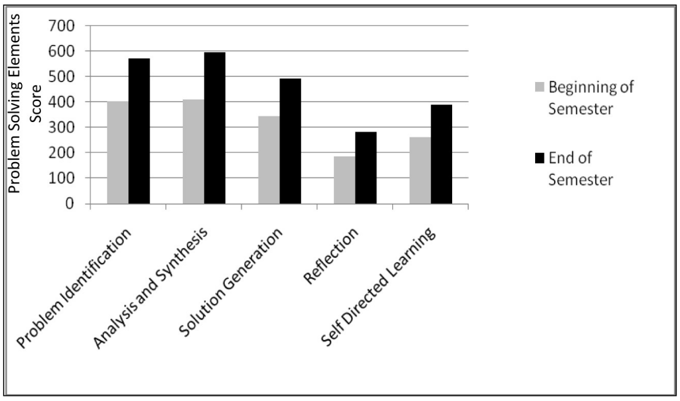

Fig. 5. Deep Thinking on Engineering Problem Solving Elements.

Table 2. Paired Sample Test Result and its Effect for Engineering Problem Solving Ability

	Paired Differences						
	Mean	**Std. Deviation**	**Std. Error Mean**	**t**	**Sig. (2-tailed)**	**p < 0.05**	**Effect Size**
Problem Identification	5.57	3.44	0.63	8.86	0.000	Sig	1.80
Analysis and Synthesis	6.27	3.86	0.71	8.89	0.000	Sig	2.09
Solution Generation	5.00	2.83	0.52	9.68	0.000	Sig	1.84
Reflection	3.20	1.75	0.32	10.02	0.000	Sig	1.59
Self-directed Learning	4.23	3.13	0.57	7.42	0.000	Sig	1.74

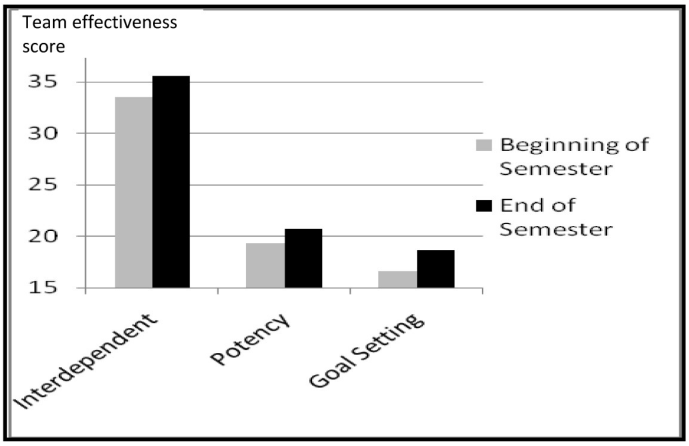

Fig. 6. Comparing Students' Team Effectiveness Scores.

were analyzed quantitatively using the Team Working Effectiveness Score (TWES) to measure improvements in team effectiveness perceived by students upon going through CPBL. In the analysis, three elements are considered: (1) interdependent, (2) potency, and (3) goal setting. As shown in Fig. 6, all the three elements score higher at the end of the semester compared to the beginning of the semester. The figure shows that the percentage increase in the scores of team effectiveness based upon student perceptions at the beginning of the semester and at the end of the semester. Referring to the figure, students' goal setting increased the most, at around 13%.

While attempting to compare mean values of statistical data using paired sample t-test, the test for normality appears otherwise. The skewness ratio for all the three elements are high, and the kurtosis ratio for potency is very high, especially at the end of the semester. Since some of the data are not normally distributed, they cannot be analyzed using parametric analysis. Therefore, the test is done using Wilcoxon Signed Ranks. Table 3 and Table 4 show the results of the test.

Wilcoxon analysis shows that there are significant differences in all the team effectiveness elements between the beginning and the end of the semester. The results are as follows:

- Interdependent: $Md_{\text{beginning of semester}} = 35.5$, $Md_{\text{end of semester}} = 36$, $z = 2.058$, $p < 0.05$, $r = 0.265$
- Potency: $Md_{\text{beginning of semester}} = 19.5$, $Md_{\text{end of semester}} = 21$, $z = 2.270$, $p < 0.05$, $r = 0.293$
- Goal Seeking: $Md_{\text{beginning of semester}} = 16.5$, $Md_{\text{end of semester}} = 19$, $z = –2.373$, $p < 0.05$, $r = –0.306$

All the effect sizes (r) are around 0.3. According to Cohen [48], effect sizes greater than 0.3 in Wilcoxon statistical analysis are considered to be large. Therefore, the test shows that there are significant differences between team effectiveness in terms of students' interdependency, potency and goal seeking, where students' team working is significantly more effective at the end of the semester compared to the beginning of the semester.

6.3 The engineering problem solving assets

Do students improve their problem solving assets, which consist of three constructs: knowledge, confidence and cognitive processes? From Fig. 7, students' deep thinking scores at the beginning are far lower than at the end of the semester. This indicates that their deep thinking improved after undergoing CPBL. The figure shows the percentage increase in the scores of deep thinking based on students' perceptions of themselves at the beginning and at the end of the semester, as abstracted from the EPSI survey. As seen from Fig. 7, the knowledge element has the highest percentage increase in deep thinking.

Test for normality using paired sample t-test shows that all skewness ratios and kurtosis ratio are within +2 and –2. Thus, all data are normally distributed, and can be analyzed using parametric analysis. From the results of paired sample statistics in Table 5, the mean values for deep thinking assets have the highest scores. As shown in the table, the paired sample t-test illustrated that there are significant differences in all the means of deep thinking, in students' knowledge, confidence and processes, at

Table 3. Descriptive Statistics of Wilcoxon Analysis

		Mean	**Std. Dev.**	**50th (Median)**
Beginning of Semester	Interdependent	33.53	6.684	35.50
	Potency	19.27	3.956	19.50
	Goal Seeking	16.63	3.718	16.50
End of Semester	Interdependent	35.60	5.593	36.00
	Potency	20.73	3.759	21.00
	Goal Seeking	18.70	2.793	19.00

Table 4. Wilcoxon Signed Ranks Test and Effect Sizes

		z	**Sig. (2-tailed)**	**p < 0.05**	**Effect Size (r)**
Pair 1	Interdependent: Beginning of Semester— End of Semester	2.058	0.040	Sig	0.265
Pair 2	Potency: Beginning of Semester— End of Semester	2.270	0.023	Sig	0.293
Pair 3	Goal Seeking: Beginning of Semester— End of Semester	2.373	0.018	Sig	0.306

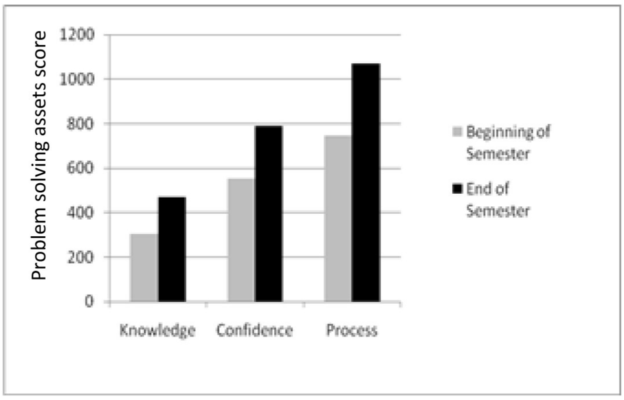

Fig. 7. Deep Thinking regarding Engineering Problem Solving Assets.

the beginning compared to the end of the semester. In summary, the t-test results are: $t(35)_{\text{Knowledge}} = 11.402; p < 0.05$, $t(35)_{\text{Confidence}} = 8.615; p < 0.05$, and $t(35)_{\text{Process}} = 9.898; p < 0.05$. These show that the mean values for students' deep learning are significantly higher at the end of the semester compared to at the beginning for knowledge, confidence and process. The effect sizes for all the comparison are also greater than 0.8. According to Cohen [48], effect sizes (d) greater than 0.8 have considerable effect in the study. This statistically proved that after going through CPBL process for one semester, students enhanced their problem solving assets to become better problem solvers.

7. Discussion

Enhancements in team-based problem solving skills are categorized based on three factors:

Factor 1: The Students' Problem Solving Elements
Factor 2: The Students' Team Working Skills
Factor 3: The Students' Problem Solving Assets

After learning using CPBL, enhancement of engineering problem solving skills can only be ensured if all these factors are significantly improved.

7.1 Factor 1: students' problem solving elements

In CPBL, problem solving elements consist of the problem solving processes, students' reflection and students' self-directed learning. Problem solving processes are problem identification, problem analysis and synthesis, and solution generation. In problem identification, students gain an understanding of the problem's domain and identify the root causes of the symptoms that they observed. In problem analysis and synthesis, students dissect and thoroughly study the problem with the objective of understanding how the problem emerged and how it grew to its current proportion, then combining the information and understanding in order to form a coherent whole [21, 49]. In solution generation, students make judgments based on the internal criteria. In their reflections, students communicate their thoughts by describing what they learned, how to improve, and the impact on their future [50]. In self-directed learning, students take control of their learning activities, directing their efforts based on their own drive to learn.

To study students' problem solving elements, the factor was quantitatively investigated by examining three questions. The questions are:

1. Do students become better problem-solvers through the process of CPBL?
2. Do students improve their ability to reflect upon the process they went through in solving problems?
3. Do students become better self-directed learners by engaging in solving problems?

In Fig. 5, at the end of the semester, the EPSI scores for all elements contributed to the enhancement of engineering students' problem solving skills. As statistically illustrated from the results of the paired t-test in Table 2, all EPSI scores in problem solving elements increased significantly. Since the EPSI scores show the degree of enhancement of students' deep thinking, the results show that students' problem solving processes, reflection and self-directed learning improved significantly upon attending a course that used CPBL.

From Table 2, the effect sizes of all the elements are greater than 0.8, which indicate that the CPBL had great effect on students' deep thinking. The students' deep thinking in problem solving processes, reflection and self-directed learning improved significantly, proving the significant impact on the students' problem solving skills. Students improved their understanding on the problems' domain, how the problems emerged and how it grew proportionally. They improved their problem solving process by knowing how to combine information and understanding in order to make better judgments in generating solutions. They also improved their thinking skills by learning how to reflect and making better judgments, thus becoming better problem solvers. The students improved their self-directed learning by assuming major responsibilities for the acquisition of knowledge and information. This result is in line with [51 and 52] on how their students perceived PBL, where the students stated that PBL prepared them well in self-directed learning, problem solving, information gathering,

Table 5. Paired Sample Test and Effect Size on Engineering Problem Solving Assets

	Paired Differences						
	Mean	**Std. Deviation**	**Std. Error Mean**	**t**	**Sig. (2-tailed)**	**p < 0.05**	**Effect Size (d)**
Knowledge	5.57	2.674	0.488	11.402	0.000	Sig	1.92
Confidence	7.87	5.002	0.913	8.615	0.000	Sig	1.76
Process	10.83	5.995	1.094	9.898	0.000	Sig	2.08

and self-evaluation techniques. This result statistically proved that, after going through CPBL process for one semester,

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

7.2 Factor 2: students' team working skills

The second factor is quantitatively investigated by examining the fourth research question:

(4) Do students improve their team working skills by solving problems cooperatively in CPBL, which leads to enhancement of their team-based problem solving skills?

As shown in Fig. 6, all the performance of all three characteristics is higher at the end of the semester compared to the beginning. Table 4 illustrates significant differences in all characteristics, with all the respective effect sizes (r) considered to be large. This suggests that students' interdependence increased, indicating that they had improved their maturity in learning and team-based problem solving by collaborating well with each other to accomplish a given task, be it in their own team or with the whole class. As shown in the potency score, students' confidence level towards their team also increased. They had the shared belief that they could effectively solve a given problem together, thus improving their effort and motivation. The test also showed that students' goal setting improved significantly at the end of the semester, meaning that students strongly believed that their team had a common objective and goal, which in turn improved their confidence in solving any complex problems together. The result conforms to the finding of a study [53], where the effect of team working on problem solving through model-eliciting activities (MEAs) yielded a positive correlation in all the three measures. The result statistically proved that, after going through CPBL process for one semester, the students improve their skills on effective team working, which leads to enhanced problem solving skills.

7.3 Factor 3: students' problem solving assets

Problem solving assets is a set of qualities that a solver has when solving a problem. Adams [24], who based her study [17], classified the assets into: (1) knowledge (2) belief, expectation and motivation; and (3) cognitive process. In CPBL, problem solving assets are considered to be an outcome of the process that students went through. It is expected that, upon going through CPBL process, students should enhance their knowledge, their confidence level, and cognitive process. Thus, the third factor is quantitatively studied by examining another question, which forms the fifth research question:

(5) Do students become better problem solvers in terms of acquiring their problem solving assets through CPBL?

As can be seen in Table 5, the effect sizes of all the elements are greater than 0.8, which indicates that CPBL had considerable effect upon the students' deep thinking in all the assets. Students' deep thinking in knowledge, confidence and cognitive process improved significantly. This means that CPBL significantly enhanced students' problem solving skills. Students acquired their knowledge which consists of components such as facts, concepts, methods, and planning, that are key features in problem solving. They improved their confidence by recognizing their strengths and weaknesses, and became internally and externally motivated. They also improved their cognitive processes while engaging in productive problem solving. This means that the CPBL approach in learning enhanced students' thinking. This statistically proved that after going through the CPBL process for one semester, students do enhance their problem solving assets to become better problem solvers as reported in [12].

Engineering problem solving skills through CPBL are categorized into three aspects: problem solving elements, team working skills, and problem solving assets. It can be concluded that upon attending CPBL classes for one semester, students enhanced their engineering problem solving skills.

8. Discussion

In the 21st century, our technological growth, the explosion of information and knowledge, and the complexity of the problems we face call for the need to produce graduate engineers with sound professional skills. One of the most important professional skills for engineers is problem solving. However, there is discrepancy between what industries require (the skills of solving workplace problems) and what normal engineering education provides (the skills of memorizing information and formulas). An inductive teaching and learning method, Problem-Based Learning (PBL) is said to take the lead in enhancing students' skills of solving workplace problems [54]. By incorporating Cooperative Learning (CL), in which students are actively and collaboratively involved in the learning process [8], in the PBL cycle, Cooperative Problem-Based Learning

(CPBL) is expected to greatly enhance students' team-based problem solving skills [47].

The development of engineering problem solving skills through CPBL is based upon three major factors: (1) problem solving elements, (2) team working effectiveness, and (3) problem solving assets. Quantitative analyses were used by administering pre and post-tests to quantitatively measure the enhancement of problem solving skills. The Engineering Problem Solving Instrument (EPSI) was developed to measure improvements of the first factor and the third factor, as perceived by engineering students. The Team Working Effectiveness Score (TWES) was used to measure the improvement of the second factor.

Qualitative analyses were carried out to study the process of enhancing team-based problem solving skills. This study reaffirmed the internal validity of the quantitative result (refer [11–13, 55] for details). Qualitative exploration illustrated how problem solving skills among engineering students were achieved through CPBL. There were a few factors which contributed to the enhancement. These factors were categorized under four themes, demonstrating how students improve their problem solving elements, motivation and learning strategies, and team working; processes which contribute to students' problem solving assets, thus enhancing their engineering problem solving skills. This finding is invaluable in providing guidance for designing a PBL environment and facilitating the teaching of engineering students. Thus, this research provides significant evidence that upon undergoing an engineering course using Cooperative Problem-Based Learning (CPBL), students enhance their team-based problem solving skills.

9. Conclusion

This study has several implications for the enhancement of problem solving skills in engineering courses. The research reinforces earlier calls to study the effectiveness of PBL in enhancing students' learning especially related to problem solving. It has provided significant evidence that problem solving skills can be enhanced through proper implementation of PBL. By incorporating CL into PBL, yielding CPBL, team-based problem solving skills can be enhanced.

The research provides a proper definition of "enhancement of engineering problem solving skills" with regards to CPBL implementation. The definition is not only limited to the "problem solving process", but also includes reflection, self-directed learning, team working, and problem solving assets. It shows that to achieve the desired learning outcome, the learning process can be brought about in a course, within one semester. This is extremely important for engineering educators, since outcomes that had once been challenging to attain through classroom-based techniques, without major curriculum revamping or infrastructure renovation, are shown to be possible with proper implementation of CPBL. Thus, small scale testing can take place using CPBL to build-up confidence in engineering educators before moving on to programme-wide curricula change that would be lasting, but require a larger investment.

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