ENHANCEMENT OF ENGINEERING STUDENTS' PROBLEM SOLVING SKILLS THROUGH COOPERATIVE PROBLEM-BASED LEARNING

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DEDICATION

To my highly respected father and mother, Allahyarham Syed Hassan Al Haddad and Allahyarhamah Sharifah Rogayah Al Habshi

To all my uncles and aunts, especially to Al Fadhil Ustaz Syed Mahayaddin, Ustaz Syed Hashim, Ustaz Syed Muhammad and Sharifah Latifah

To my beloved wife and children, Khairiyah Mohd Yusof, Sharifah Ruqayyah, Sayyid Sofwan, Sayyid Muhammad and Sharifah Sarah Yusra

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ABSTRACT

The purpose of this research is to investigate the enhancement of problem solving skills among engineering students that went through a course using cooperative problem-based learning (CPBL) teaching methodology. In the study, both, quantitative and qualitative analyses are used. The quantitative analysis is used to find the evidence and the extent of the enhancement. Based upon the theoretical framework, enhancing problem solving skills through CPBL is achieved through three factors: problem solving elements, motivation and learning strategies, and team working. The evidences of enhancement are based upon the level of cognitive thinking exercised by a class of third year students who took Process Control and Dynamic course. Pre and post-tests questionnaires are used to investigate the enhancements. Since there is hardly any suitable instrument to evaluate the enhancement of problem solving elements for students after undergoing CPBL, the Engineering Problem Solving Instrument (EPSI) was developed. The available Motivated Strategies for Learning Questionnaire (MSLQ) and Team Working Effectiveness Score (TWES) are used to study the enhancement of students' motivation and learning strategies, and effectiveness of team working, respectively. The results of the quantitative analyses show significant enhancements of all the three factors. Qualitative analysis is used to investigate the reason behind the enhancement. Three types of instruments are used to gather data, which are; a series of reflections, semi structured interview questions, and test answer scripts. Seven students are purposely selected to study the phenomena. Data are analyzed using the grounded theory technique and was triangulated for validity and reliability. The results and themes emerged in the analyses also triangulated the quantitative analysis. Sub-models of all spotlights emerged in the qualitative analysis are proposed. Results show that the enhancements of problem solving skills among engineering students through CPBL are caused by the three important factors, which are inter-twined with one another. The CPBL cycles incorporated with problem solving cycles motivates students and improved their learning strategies, making them better problem solvers. To overcome the challenge of CPBL, a proper CPBL implementation is required. Findings show that the proper implementation of CPBL requires four stages, which are building, bridging, extending and applying. Missing one of the stages will limit the learning outcomes, especially the problem solving skills. This research recommends an effective framework for CPBL implementation and proposed promising practices for engineering educators to enhance the most important assets of our future engineers, which is the skill to solve unexpected novel problems with unexpected creative solutions.

ABSTRAK

Penyelidikan ini bertujuan untuk mengkaji peningkatan kemahiran penyelesaian masalah bagi pelajar kejuruteraan yang mengikuti kursus yang menggunakan pendekatan pembelajaran berasaskan masalah secara berkumpulan (CPBL). Kajian ini menggunakan analisis kuantitatif dan kualitatif. Kajian kuantitatif digunakan untuk menilai peningkatan tahap kemahiran penyelesaian masalah. Berasaskan kepada kerangka teori, terdapat tiga faktor penyebab kepada tertingkatnya kemahiran penyelesaian masalah melalui CPBL. Faktor-faktor tersebut adalah elemen penyelesaian masalah, motivasi dan strategi pembelajaran, dan pembelajaran berkumpulan. Bukti peningkatan ini berpandukan kepada tahap pemikiran kognitif pelajar tahun tiga yang mengikuti kursus Kawalan Proses dan Dinamik. Ujian pra dan pasca digunakan untuk menilai tahap peningkatan kemahiran penyelesaian masalah. Disebabkan hampir tiada instrumen untuk menilai tahap peningkatan elemen penyelesaian masalah, ia telah dibina dan dikenali sebagai EPSI. Dua lagi faktor dinilai menggunakan instrumen MSLQ dan TWES yang sedia ada. Berasaskan analisis ini didapati terdapat peningkatan yang signifiken bagi ketiga-tiga faktor tersebut. Bagi memahami bagaimana penomena in boleh berlaku, maka analisis kualitatif dijalankan. Tiga jenis instrumen iaitu beberapa siri refleksi pembelajaran, soalan temubual separa berstruktur, serta kertas jawapan ujian dan peperiksaan telah dianalisis. Tujuh orang pelajar telah dipilih secara bertujuan untuk kajian ini. Data dianalisis menggunakan teknik "*grounded theory*" dan ditriangulasikan untuk tujuan kesahan dan kebolehpercayaan. Keputusan yang diperolehi serta terma yang terhasil menunjukkan ujud triangulasi antara analisis kualitatif dan analisis kuantitatif. Berpandukan kepada analisis kualitatif, model separa bagi setiap faktor dihasilkan. Kajian menunjukkan peningkatan kemahiran penyelesaian masalah adalah disebabkan oleh integrasi dan perkaitan antara ketiga-tiga faktor ini. Penggabungan CL dan PBL melipatgandakan kemampuan CPBL dalam meningkatkan kemahiran penyelesaian masalah di kalangan pelajar-pelajar kejuruteraan. Untuk mengatasi cabaran CPBL, perlaksanaan yang betul diperlukan. Integrasi antara kitaran CPBL dengan kitaran penyelesaian masalah meningkatkan motivasi serta strategi pembelajaran pelajar, sekaligus meningkatkan kemahiran dalam penyelesaian masalah. Perlaksanaan CPBL yang betul memerlukan empat fasa, iaitu fasa pembinaan, penggabungan, pengembangan dan perlaksanaan. Kekurangan mana-mana fasa akan menghadkan hasil pembelajaran, terutama sekali kemahiran penyelesaian masalah. Berdasarkan hasil kajian, kerangka perlaksanaan CPBL yang efektif dicadangkan. Kajian juga mencadangkan perlaksanaan amalan-amalan yang baik kepada pendidik kejuruteraan untuk meningkatkan aset yang terpenting bagi jurutera masa depan, iaitu kemahiran menyelesaikan masalah rumit yang di luarjangkaan dengan jawapan kreatif yang di luarjangkaan.

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LIST OF ABBREVIATIONS

A&S	Analysis and Synthesis
ABET	Accreditation Board for Engineering and Technology.
ASEE	American Society for Engineering Education
CL	Cooperative Learning
COSEPUP	Committee on Science, Engineering, and Public Policy
CPBL	Cooperative Problem-Based Learning
EAC	Malaysian Engineering Accreditation Council
EPSI	Engineering Problem Solving Instrument
HEFCE	Higher Education Funding Council of England
HPL	How People Learn
IDEAL	Identify, Define, Explore, Act and Look-back
IEA	International Engineering Alliance
IET	Institute of Engineering and Technology
IT	Information Technology
KNL	Known - Need to Know - Learning Issues
MPS	McMaster Problem Solving
MRIQ	My Role Is Questionnaire
MSLQ	Motivated Strategies for Learning Questionnaire
NAE	National Academy of Engineering
NVivo	(Qualitative data analysis software package produced by QSR International)
PBL	Problem-Based Learning
PI	Problem Identification
PSA	Problem Solving Assets
MLS	Motivation and Learning Strategies
PSE	Problem Solving Elements

PSP	Problem Solving Process
SDL	Self-directed Learning
SG	Solution Generation
SOLO	Structure of Observed Learning Outcome
SPSS	Statistical Package for the Social Sciences
TEPS	Tests and Examination for Process Skills
TWE	Team Working Effectiveness
TWES	Team Working Effectiveness Score
UK	United Kingdom
USA	United States of America
UTM	Universiti Teknologi Malaysia
UTM-PBL	Universiti Teknologi Malaysia – Problem-Based Learning

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The purpose of this research is to investigate to what extent a hybrid approach of Cooperative Learning (CL) and Problem-Based Learning (PBL), called Cooperative Problem-Based Learning (CPBL), does enhance problem solving skills among engineering students. While attempting to do so, the question of how the CPBL approach developed problem solving skills will also be scrutinized. Past research on enhancing problem solving skills focused mainly on stand alone, institutionalized courses (Woods, 1996; Jonneson, 2004). With regards to PBL teaching methodologies, most of the past research focused on the studies of the effectiveness of PBL versus traditional learning on students' academic performance (Strobel and Barneveld, 2009). This research is investigating the effectiveness of CPBL in enhancing problem solving skills if applied to a typical content-based classroom setting and how it occurs. This study is important to provide empirical evidence in educational innovation for the advancement of engineering education. This chapter sets the direction by describing the background, statement of problem, purpose, significance and scope of the research.

1.2 Background

Graduating engineers today face numerous challenges when they enter a world marked by rapid and global changes. The challenges include dynamic technological development, innovation and change, exponential advancement in information and computer technologies, and increase global participation and competition (NAE, 2005; Duderstadt, 2008). In addition, to remain competitive, industries produce over thousands of new products a year that cause existing products to quickly become obsolete, leading to the gradual reduction of product development time. Thus, graduate engineers need to be prepared with information mining, knowledge integration, and ideas creation. They must be able to take a holistic approach to problems involving complex and ambiguous systems, and to employ creative problem solving skills (Katehi, 2005). In an increasing global work, engineering graduates are expected to work on multinational teams, to have global perspective, and to be culturally and linguistically literate (Spinks, Silburn, and Birchall, 2006; Duderstadt, 2008). All these factors put current engineering education under pressure. To be competitive and taking role of leaderships today and in the future, engineering graduates must have world class engineering education, be equipped with the latest technical knowledge and tools, and have adequate understanding of the social, economic and political issues that affect their work. Analysis of responses to a question concerning five most important skills required for the current graduate engineers show that the top six out of more than fifty different skills are communications, technical ability, creativity and innovation, analytical skills, people management and problem solving (Spinks, Silburn, and Birchall, 2006).

For today's engineers and in the future, they have to face open-ended problems with no single correct answer. Therefore, they have to be innovative and be able to find the best solutions to the problems that they might have never experienced before. However, in today's engineering education, problems that engineering students encounter in classroom are usually well-structured, which are inconsistent with the problems they will face later (Brickell and Herrington, 2006). For example, project work is viewed as important in developing problem solving skills. However, in most cases, the projects given were limited and lack real issues of the working environment (Spinks, Silburn and Birchall, 2006). Usually, projects given in universities are around solving well-structured problems. Not on how the problem came about, the direction they were expected to go in, and what are real factors in the solution should be. So, while project work is seen as important, it needed more relevance and practicality.

The inconsistency between what learners require (complex, ill-structured problem-solving experience) and what traditional education offers, signifies a complex and ill-structured problem (Jonassen, 2000). In the opinions of engineering managers, problem solving are evaluated as one of the most important skills of an engineering professional, and are becoming even more vital in the extremely challenging world of today (Spinks, Silburn, and Birchall, 2006). The only way to cope with this pressure efficiently is by acquiring advanced thinking and enhancing problem solving skills. Thus, there is an urgent need to prepare future engineers for solving unknown problems. Hence, the emphasis should be on teaching to learn rather than providing more knowledge. Teaching engineering students 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 technological breakthroughs (Katehi, 2005).

Spurred by these growing pressures, in 1997 the ABET, which is the United States of America's (USA) accreditation board of engineering and technology, who sets and monitor standards for American engineering degree programs, adopted a new set of outcomes-based program evaluation criteria (ABET, 2000). Criteria 3 of ABET's listed 11 attributes that graduates of accredited engineering programs should possess. With respect to problem solving skills, the ABET (2011) criteria 3 (a) and (e) state that students should demonstrate (a) the "ability to apply knowledge of mathematics, science, and engineering", and, (e) the "ability to identify, formulate, and solve engineering problems" A modified version of the prescribed ABET outcomes has been adopted by signatories of the *Washington Accord* (2011). Washington Accord is a multinational agreement that recognize the substantial equivalency of the signatory members' accreditation system, the engineering programs they accredit, and the fitness of the graduates of those programs to practice engineering at the entry level. Currently, among the full members of the Washington

Accord are the USA, United Kingdom (UK), Canada, Ireland, Australia, New Zealand, Hong Kong, South Africa, Japan, Singapore, Korea, Taiwan, Malaysia and Turkey (Washington Accord, 2011). The Washington Accord has listed 12 attributes their engineering graduates should have, and the first four of the list are with respect to problem solving. The first in the list as mentioned in IEA (2009):

"Graduates of the program must demonstrate the ability to apply mathematic, sciences and engineering sciences for design, operation and improvement of systems, processes and machines; formulate and solve complex engineering problems"

At the same time empirical studies of teaching and learning, and brain research had provided increasingly strong evidence that the traditional lecture-based method of education was ineffective at facilitating development of those skills (Felder, 2005; Katehi, 2004). To achieve the program outcomes as required by engineering accreditation body, such as ABET, the Washington Accord, and the Malaysian Engineering Accreditation Council (EAC), engineering courses must implement various methods in teaching and learning. Active and constructive learning are reported to address the development of the required skills (Prince and Felder, 2007; NAE, 2005; Prince, 2004; Felder and Brent, 2004a; 2004b; Dewey, 1964; Piaget, 1954). Cooperative learning (CL) and Problem-Based Learning (PBL), for example, are more learner-centered modes of active and constructive learning that have the potential to help engineering students to cope with the challenges mentioned above (Felder and Brent, 2007; Johnson, Johnson and Smith, 2006; Lattuca et.al., 2006; Woods et.al., 2000; Slavin, 1996). The essence of CL is the principles of effective team working (Johnson, Johnson and Smith, 2006; Felder and Brent, 2007), while supporting each member in learning and producing high quality work. PBL is the move beyond mental understanding to applying concepts to real life (Yadav, 2011). It develops students' ability to solve ill-structured problems, increases critical thinking and communication skills. PBL provides students with self-directed learning skills that can be used to acquire new skills and knowledge as engineers. By integrating both, CL and PBL, the Cooperative Problem-Based Learning (CPBL) is expected to escalate the process of enhancing the required skills of future graduate engineers, especially the problem solving skills (Mohd-Yusof and Helmi, 2008).

In order to understand the challenges and potential resolutions, the National Academy of Engineers (NAE, 2004; 2005), Duderstadt (2008) and Spinks (2006) produced reports on the challenges of the future engineering practices and its educational need. Jonassen (2006) directed his work "towards design theory of problem solving" to come up with how to prepare our future engineer to solve work place problems. Strobel and Barneveld (2009) urged engineering education researchers to better understand the nature of work place problem solving especially for instructional and educational approaches that emphasize problems like PBL. Savery and Duffy (2001) related constructivism (which is the philosophical view of how people came to understand), to the practice of instruction. He examined PBL, which he considered as the best exemplars of constructivist learning environment. All these issues are discussed in more detail in the next chapter.

1.3 Problem Statement

There is no doubt that problem solving skills are essential for engineers (Woods, 1996; Jablokow, 2007). Looking at the increasing difficulty and the complexity of current problems, engineers must work effectively in teams (Spinks, Silburn, and Birchall, 2006; Wayne, 2004). However, there are many complaints about the lack of the skills in the current engineering graduates (Woods et al., 1997; 2000; Katehi, 2004; Katehi, et al., 2005; Wayne, 2005; Spinks, Silburn, and Birchall, 2006; Duderstadt, 2008). Many organizations and industries have to conduct problem solving courses and on the job training for their new engineers, on their own, which these new engineers should have already acquired in universities (Department of Education, Training and Youth Affairs, 2000; Mina, Omidvar and Knott, 2003; Nguyen, Yoshinari, and Shigeji, 2005; Casner-Lotto and Barrington, 2006; Zaharim, et al., 2008). The question is what is the best way to prepare our engineering students with the skills? As methodologies that heavily emphasize on problems and team-based learning, PBL and CL are said to be the possible solutions (Prince, 2004; Smith, et. al., 2005; Duderstadt, 2008) Although a large number of research studies have been carry out to examine the effectiveness of PBL on students' performance by comparing with other forms of instruction (see for examples Sahin and Yorek, 2009; Mohd-Yusof and Helmi, 2010; Yadav, et.al, 2011), there is no consensus on how and to what extend it enhance the problem solving skills. If it does, it is more on a problem solving as a separate, stand-alone course, where there are heated debates on transferability of the skills (Woods et al., 1997). Although some studies and some findings exist on the effect that CL and PBL have on students' academic performance (Woods, 2000; Norman, 2000; Helmi et. al., 2004; Mohd-Yusof et.al., 2005), but up to this date, there is no research studies the effect of PBL on engineering students' problem solving skills for a typical content-based classroom. Strobel and Barneveld (2009) in their intensive meta-analysis of PBL papers advised researchers to shift from studying PBL versus normal learning, to research on the effectiveness of PBL in enhancing students' learning especially related to problem solving. Therefore, the intention of this research is to investigate to what extent the hybrid approach of CL - that heavily emphasize on team working, and PBL - that heavily emphasize on problem solving, also known as the CPBL approach, does enhance engineering problem solving skills. While attempting to do that, it will investigate how the approach developed problem solving skills among engineering students.

1.4 Research Questions

Based on the problem statement, this research would like to study and find answers to the following questions:

i. To what extent the CPBL approach enhance problem solving skills among engineering students?
ii. How does the CPBL approach develop problem solving skills among engineering students?

The answers lead to the development of a model represents how problem solving skill can be enhanced through CPBL among engineering students.

1.5 Research Objectives

To date, hardly any research is found that rigorously investigate the relationship between the practices used in PBL and its outcomes on problem solving skills in a typical content-based, middle-size engineering classroom. Literatures indicate that although students and lecturers reported improved problem solving skills in PBL, these findings were obtained from students' and faculties' perspectives rather than any quantitative or qualitative measures of problem solving skills. None of these studies provide detailed definition of problem solving skills or describe the meaning "improved" problem solving skills held for students as a result of the PBL experience. The exact nature of the practices that successfully facilitated student's problem solving skills in PBL remains unknown. The aim of this research is to:

i. Investigate the effectiveness of CPBL approach in enhancing engineering students' problem solving skills.
ii. Study the significance of the CPBL practices and the influence of these practices may have on enhancement of engineering students' problem solving skills.

Based on the finding, it is the intention of the researcher to propose a model for engineering educators to effectively implement CPBL in classrooms, in order to enhance problem solving skills among engineering students.

1.6 Theories Governing Conceptual Framework

Conceptual framework for this study is mainly governed by theories and studies about preparing future engineers and its challenging world as extensively reported by the National Academy of Engineering (Wayne, 2004; 2005), the Royal Academy of Engineering (Spinks, Silburn and Birchall, 2006), Duderstadt (2008) and Vest (2008, 2010); problem solving skills in engineering educations (Woods, 2000, Jonassen, 2000; Jonassen, Strobel and Lee, 2006; Adams, 2008 and Phillips, 2008); cooperative and problem-based learning (Johnson, Johnson and Smith, 2006;

Barrows, 2002; Barrow and Tamblyn, 1980; Hmelo-Silver, 2004; Woods, 1994; 1996; 2000; Savery, 2006)

1.6.1 Theoretical Underpinning the Challenges and Attributes of Future Engineers and Engineering Education

The engineers of tomorrow, and in fact today, will face great challenges. Today, the world is facing technological and social challenges in the areas such as biotechnology, nanotechnology, photonic, information explosion, communication technology, globalization, population and demographics, health care, and security. There will be more dramatic challenges in the future, such as environmental contamination, infrastructural damage, and telecommunications breakdown (Vest, 2008; Duderstadt, 2008). Each day, engineers will have to deal with the stress of contending in the fast-paced of change called global knowledge-based economy. They will face even bigger challenges because they need to solve these global problems of unprecedented scope and scale, where they have to perform and innovate at ever accelerating rate.

More than that, they need to face new engineering frontiers, what Vest (2010) called the tiny system and macro system. The tiny systems are those associated to the nano-technology where things get ever smaller, faster, and more complex. Macro systems are work connected to systems that greatly affect society, such as energy, water, environment, communication, and logistic. Thus, most of the work of our future engineers will be to move this tiny systems technology into macro systems application (Vest, 2010).

The first report of Engineers 2020 (Wayne, 2004) offers a glimpse of what engineers need to be able to do in the coming years. This report specifically points out that engineers must be able to function as team members. While stressing that an ability to communicate is an attribute of the engineer of 2020, 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".

The Engineers 2020 (Wayne, 2004) lists significant characteristics that will support the success of engineering profession in 2020 and beyond". The first three and the last three are with regards to problem solving, the fourth, sixth and seventh are related to team working. All of these characteristics are believed can be achieved through CPBL. The significant characteristics are as follows:

i. Possess strong analytical skills
ii. Exhibit practical ingenuity
iii. Creative
iv. Good communication skills
v. Master the principles of business and management
vi. Understand the principles of leadership
vii. High ethical standards
viii. Professional
ix. Dynamic, agility, resilience and flexible
x. Lifelong learners

In the twenty first century engineering fields are enormously exciting and richer. Its perspective and substance become more complex. Looking at the challenges, it is important to realize that students of the 21st century are full of interest, commitment and ambitions (Katehi, et al., 2004). Even though it is difficult to predict exactly what the engineering students should be taught, the environment can be focused in which they learn, and situations to which they are exposed (Spinks, Silburn, and Birchall, 2006).

1.6.2 Theoretical Underpinning of Problem Solving and Problem Solving Skills Enhancement in Engineering Education

Most educators and educational psychologists believe that problem solving is the most important learning outcome for human being. As stated by Gagne (1980), “the central point of education is to teach people to think, to use their rational powers, to become better problem solvers". This is because everyone solves problems, moreover for engineers. Engineers should be creative problems solvers (Vest, 2008). Nevertheless, today’s engineering educations emphasize more on memorizing information and formulas. In today’s work culture, professionals are never paid for memorizing facts or completing exams. Ironically, exams are still the primary indicators of academic achievements. Students are seldom, if ever, required to solve actual work problems in their curriculum. Problems that they often solve in universities are unfortunately inconsistent with the nature of actual problems which they are supposed to solve in their everyday lives.

The reason learners face difficulties when engaged in problem solving was inquired by Jonassen and Hernandez-Serrano (2002). According to them, a crucial reason is the lack of understanding in problem solving activities. As a result, educators are unable to optimally support learners in it. In the “Toward a Design Theory of Problem Solving”, Jonassen (2000) explained the range of problem solving outcomes by describing the difference of well-structured and ill-structured problems in the context of their instructional design requirements. A well-structured problem tends to have an instructional design which is rooted in information-processing theory. This theory generalizes learning outcomes as skills that can be applied in a multitude of domains. In contrast, an ill-structured problem tends to share theory with constructivist and situated cognition. This reasons that learning outcomes are not multi-domain but instead should have a specific domain for each performance. Therefore, Jonnesen (2000) recommends embedding instructions in a genuine context.

Problems are different in their nature and components. Also, problems vary in their representation and interaction among them. Mayer and Wittrock (2006) differentiate problems as ill-defined versus well-defined and routine versus non-routine, while Jonassen (1997) distinguish well-structured from ill-structured problems and enunciated differences in cognitive processing used. Smith (1991) distinguished between internal and external factors in problem solving. External factors are the variations in problem type and representation. Internal factors are those that describe variations in the problem solvers.

Some of the characteristics of learners that may affect problem solving as categorized by Jonassen (2000) are: (i) familiarity – solvers' familiarity with the problem type (the experts verses the novices); (ii) Domain and Structural Knowledge – solvers' level of structured knowledge, well-integrated domain knowledge is essential for problem solving; (iii) Cognitive Controls – represent pattern of thinking that control the way an individual process and reason about information; (iv) Meta-cognition – the awareness of how one learns, the ability to judge the difficulty of a task; (iv) Epistemological Beliefs – the understanding belief about knowledge and how it develop; (v) Affective and Conative – affective: attitudes and belief about the problems, domain and learners' ability to solve problems; conative: motivation, exerting effort, persisting on task. He also described eleven different problem-types mapped on a four-dimensional scale (Jonassen 1997; 2000; Jonassen, Strobel and Lee, 2006). Mayer and Wittrock (2006) and Adams (2008) had categorized these into three domain; (1) knowledge, (2) beliefs, expectations and motivation, and (3) cognitive process.

In general, engineering problem solving process is divided into three phases; the definition phase, the strategy phase and the solution phase (Phillips, 2008). The definition phase is where problem solvers identify all the unknown and known information related to the problem. The strategy phase is where problem solvers apply the information gathered from the problem definition to the problem through generation of several solution alternatives. The solution generation phase is where problem solvers interpret the results of the analyses and recommend solution to the problem.

In "Everyday Problem Solving for Engineering: Lesson for Engineering Educators", Jonassen, Strobel and Lee (2006) identified 12 attributes of work place engineering problems. They also explicated some of the parameters of everyday, work place engineering problem solving. Those parameters should be used by engineering education programs to design learning experiences to better prepare students to meet the challenges of ABET and the Engineer of 2020. One of these solutions is by converting curricula into PBL (Jonassen, Strobel and Lee, 2006).

However, Woods in his book “How to Gain the Most from PBL” warned about the 8-steps “grieving” process students will go through in PBL (Woods, 1994). This process is similar to symptoms of someone who has gone through a major trauma or change, such as losing a family member through death. Students’ motivation and attitude towards learning do have great influence in the grieving process. In return, coping/struggling with this will help them in their lifetime living (Woods, 1994). Woods found that problem solving skills are best developed through three-stage process: (1) build; (2) bridge; and (3) extend, through PBL methodology (Woods et al., 1997).

These extensive reviews are used in understanding problem solving and development of problem solving skills. As Strobel (2007) mentioned in his paper, understanding problems and problem solving is essential in order to better design problems, better design support structures for students engaging in learning, and research the effectiveness on students’ performance and conceptual development.

1.6.3 Theoretical Underpinning of Cooperative Learning and Problem-based Learning

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. In terms of group performances, Smith and Imbrie (2004) had classified four levels of group performance, with pseudo-group as the worst, followed by traditional group, while the effective groups are cooperative group and high-performing cooperative group. Proper implementation of CL will guide students to form a group that is in the third and fourth levels of group performance.

Johnson, Johnson and Smith (2006) defined five principles of cooperative learning which are: (1) positive interdependence, (2) individual accountability, (3) face to face interaction, (4) appropriate interpersonal skill, and (5) regular assessment of team functioning. As reported in Smith and Imbrie (2004), Johnson and Johnson (1991) listed seven methods used by groups to make decisions in solving problems where consensus is considered the most effective. They also listed five characteristics of effective decisions which are: well used of resources, well used of time, making correct and high quality decisions, and the problem solving ability of the group is enhanced. In making collective decision, Garvin and Roberto (2008) suggested it should be viewed as an inquiry approach rather than as an advocacy process, so that decision making is seem as collective problem solving rather than as a competition.

PBL in its current form originated as a response to low enrollments and general dissatisfaction with medical education (Barrows, 1996). Since its origin, PBL has been used in a variety of disciplines and educational levels, including engineering. There are many reports on PBL, see Barrows (1996) and Savery (2006) for definition; see Savery (2006) for a history; see Savery and Duffy (1995) for an introduction; see Hung, Jonassen & Liu (2007) for a summary of the research; see Strobel and Barneveld (2009) for meta-analysis comparing PBL to conventional classroom; and see Kirschner, Sweller and Clark (2005) for critics).

PBL has gained world-wide interest as an innovative technique to encourage deep learning and a multitude of crucial professional skills essential in engineering graduates (Strobel, 2007). Contrary to the conventional model that places an application problem after concepts or topics have been introduced, PBL uses the problem to initiate learning. Although it is commonly agreed that PBL starts with a problem, there are various different models, and thus a kaleidoscope of implementation techniques in PBL.

Barrow (1996) states that PBL has taken on various forms which are the consequence of modifications made by organizations from time to time in order to adapt to specific situations. However, the following points were noted in Barrows' (2002) definitions of PBL: (i) Corresponding to the ill-structured cases which are presented as unresolved, students are able to not only produce thoughts on what causes the problem, but also what needs to be done in order for them to be solved; (ii) By using the student-centred approach, students themselves have to identify what knowledge and information they need in order to solve the problem. They are independently extracting out key points, identify their unknown are of knowledge, and search and obtain the required knowledge; (iii) Instructors guides students by giving them meta-cognitive questions, which in the following classes recede; (iv) Legitimacy influences the core of problem selections, encompassed by linearity with real-world application.

The definition of PBL in this research is guided by Barrows (2002), as described above, and by Savery (2006) who states that it is "an instructional (and curricular) learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" As opposed to PBL, the researcher considered traditional learning approaches to be instructor-driven, lecture-based deliveries within a curriculum.

The Cooperative Problem-based Learning (CPBL) approach is a combination of CL and PBL to emphasize learning and problem solving in small student teams consisting of 3-5 students, with one academic staff taking the role of a floating facilitator (Mohd-Yusof and Helmi, 2008). The small groups in a medium to large classes PBL models with floating facilitators implemented in some institutions such as University of Delaware, USA; Temasik Polytechnic, Singapore; and Universiti Teknologi Malaysia, Malaysia. CPBL approach is an inductive learning, team-based approach that focuses on developing thinking and learning skills in students. Unstructured problems, which may be real or simulated realistic ones, are used as the starting point of learning. This should creates deep interests among students to learn together new knowledge and integrate existing ones, and forcing them to think critically and creatively to solve problems (Tan, 2004; Woods, 1996, Woods, 2000, Hmelo-Silver, 2004, Adams, 2008). A CPBL learning environment can easily accommodate all the desired generic skills outcomes required by professional bodies such as Malaysian Engineering Accreditation Council (EAC) and ABET. Nevertheless, the strength of CPBL lies in shaping attitudes as well as creating interest and excitement in learning otherwise dry content, and motivating students to cultivate interdependence in learning, thinking and problem-solving together in their teams and among teams. Detail description of the approach is discussed in Chapter 4.

1.7 The Conceptual Framework

On integrating all the above underpinning theories, the researcher suggests the conceptual research framework as shown in Figure 1.1. The ability to solve problems is the main skill required by a creative, innovative and practical engineer. Referring to the figure, the integration of CL and PBL implementation, with engineering problem solving, is expected to enhance problem solving skills among engineering students. This is done by infusing series of CPBL cycles and problem solving cycles, thus enhancing the students to become effective problem solvers. The research hypothesized that the approach will contribute to the development of our future engineers in their ability to solve real world problems. Three main theories underpinning the study are (1) the characteristics of future engineers as effective problem solvers in terms of cognitive, affective and professional domains; (2) the process, elements and assets of engineering problem solving; and (3) the integration of CL and PBL, named CPBL; which are elaborated in the literature reviews.

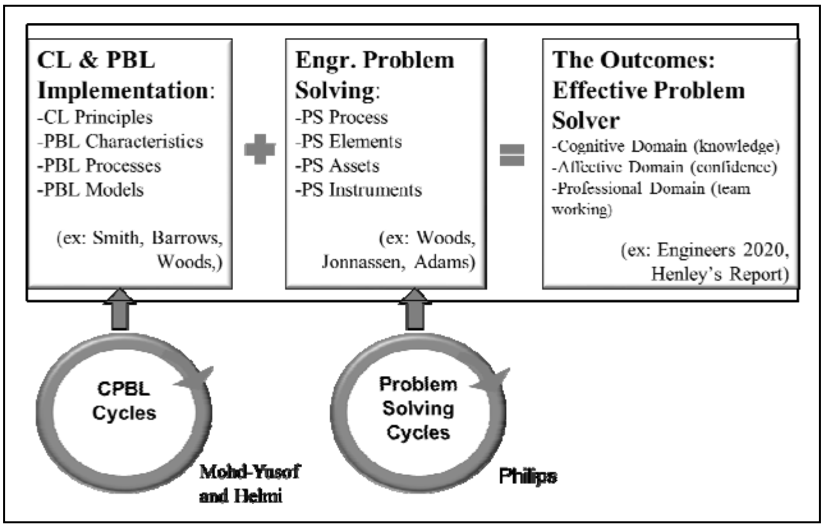


Figure 1.1: Conceptual research framework

The characteristics of the future engineers as reported in the Engineers 2020 phases I (Wayne, 2004) and II (Wayne, 2005), the Engineering for Changing World (Duderstadt, 2008), and the Royal Academy of Engineering (Spinks, Silburn, and Birchall, 2006), are used as guidelines in developing course outcomes. A medical educator at McMaster University, Canada, Howard Barrows, developed PBL approach to instruct medical students in how to approach and solve clinical problems (Barrows, 1980). The philosophy was then applied to engineering education by Woods in his McMaster Problem Skills (MPS) program (Woods, 1996).

The MPS is an institutionalized program, where it distributed "problem solving workshops" throughout the program. These are separate, stand-alone courses. Although the MPS program a good model for enhancing problem solving skills, it needs an institutional commitment. Unlike Wood's, the CPBL approach is expected to developed the skills when students are learning the content in a course. It is under the sole control of a lecturer (i.e. facilitator), without necessarily institutionalizing the approach in the course syllabus. Because of the flexibility of the CPBL approach, the outcomes of a course can be formulated as desired. The problem solving and CPBL process are divided into four cycles. Cycle 4 should prove the mastery level. The first 3 stages are expected to upgrade problem solving skills progressively. This is based on Wood's (1996) three-stage processes, which are build, bridge and extends.

The CL philosophy of Johnson, Johnson and Smith (2006) and PBL theories of Barrow (2002) and Woods (2000) are used as key references in the study with respect the attributes, motivation and learning strategies of CPBL approach. Team dynamics and functions by Smith and Imbrie (2004) and Johnson, Johnson and Smith (2006) are used as key reference of team-based problem solving skills. Instructional-design model by Jonassen (1997), McMaster model by Woods, et al. (1997), engineering problem solving process by Phillips (2008), problem solving assets by Mayer’s and Wittrock’s (2006) and Adam’s (2008) are used as main guidelines in the development of problem solving instrument.

1.8 The Theoretical Framework

In order to educate future engineers to become better problem solvers, the theoretical underpinnings and the conceptual framework are illustrated in a theoretical framework as shown in Figure 1.2. The framework highlighted the success factors for enhancing problem solving skills. The factors are issues related to problem solving elements, the supports from peers or team members, and students’ motivation and learning strategies. These three important factors are supported in CL and PBL teaching methodologies. Thus, by using CPBL, which is the integration of CL and PBL, it is expected that engineering students will acquire problem solving assets.

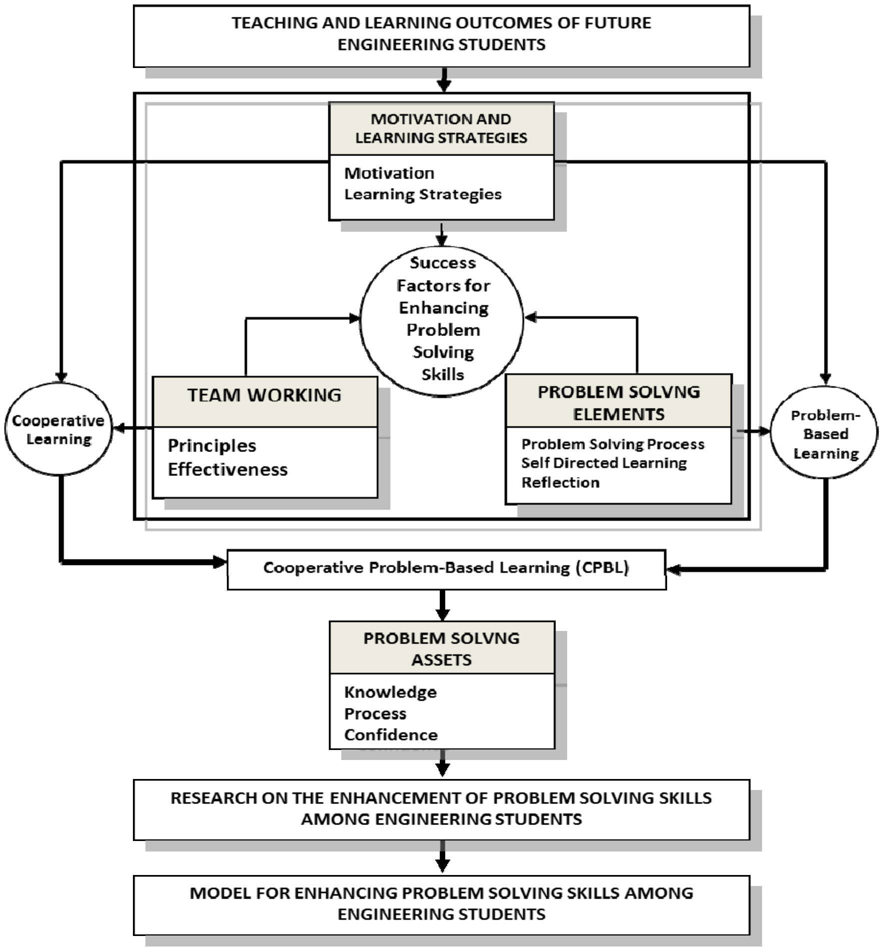


Figure 1.2: Theoretical framework for enhancing engineering students' problem solving skills

1.9 Significance of the Study

This study has numerous implications on the enhancement of problem solving skills in engineering. Research provided here 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 with PBL through CPBL, the engineering problem solving skills can be exponentially enhanced. The research has provided a proper definition of "enhancement of engineering problem solving skills" with regard to CPBL implementation. The definition is not only limited to "problem solving process" per se, but also includes reflection, self-directed learning, motivation and learning strategies, and team working. It shows that to achieve the desired learning outcome, the learning process can be done in a course, within one semester, without the need to invest in a big change, be it in the curriculum or facilities. This is extremely important for engineering educators, because outcomes that were challenging to attain through classroom-based techniques, without major curriculum revamp or infrastructure renovation, has now been shown to be possible with proper implementation of CPBL. In addition, the framework of how students actually develop these outcomes will assist those implementing CPBL on the important aspects in planning and providing guidance through facilitation and scaffolding activities. Thus, small scale testing can now take place using CPBL to build-up confidence in engineering educators before moving on to programme-wide curricula change that would be lasting.

Apart for the two main contributions mentioned above, the study also contributes towards:

i. Development of engineering problem solving instrument, named as Engineering Problem Solving Instrument (ESPI).
ii. Formulation of enhancement of engineering problem solving skills equation.
iii. Development of model for enhancing engineering problem solving skills.

1.10 Scope of the Study

Study is done with a core engineering course as to engage to the “real” engineering problem solving processes, where a variety of engineering principles applied. Process Control and Dynamic subject is selected as it is a required, third or final year course for many engineering programs such as mechanical, electrical and chemical engineering. Department of Chemical Engineering at the University Teknologi Malaysia applied CPBL as mode of learning in its Process Control and Dynamic curriculum since 2003. Therefore, it is used as the case study in this research. The research covers process of enhancing problem solving skills and its related aspects. The study does not cover other factors such as students’ social background, cultural and ethnical differences that may affect the students' performance.

1.11 Definition of Terms

Among the terms that exceptionally important in this research are defined in this section. Other important terms are provided in the glossary of this thesis.

Constructivist Theory

It is "a psychological theory of knowledge which argues that humans construct knowledge and meaning from their experience. It is a theory describing how learning happens, regardless of whether learners are using their experiences to understand a lecture or following the guidance from lecturer by experiencing it". Constructivist theory suggests that "learners construct knowledge out of their experiences. It is often associated with pedagogic approaches that promote active learning. It views learning as a process in which the learner actively construct new ideas or concepts based upon current and past knowledge. Constructivist learning, therefore, is a very personal endeavor, whereby internalized concepts, rules, and general principles may consequently be applied in a practical real-world context. Lecturer acts as a facilitator who encourages students to discover principles for themselves and to construct knowledge by working to solve realistic problems". It generally attributed to Jean Piaget who developed a constructivist theory of cognitive development. According to Piagetian theory, cognitive growth occur through the process of adaptation and proceeds through the processes of assimilation (a process in which event is brought into someone thinking) and accommodation (a process in which low-level representations are converted into higher-level representation) (O'Donnell, Reeve and Smith, 2009).

Social Constructivist

Social constructivist is one form of constructivist theories where learners construct knowledge in a social context (O'Donnell, Reeve and Smith, 2009). "It describes knowledge being constructed by learner as a result of the continual interaction between the individual and his social world and environment". It concerned with how we learn from others. It is best illustrate by Vygotsky's theory of cognitive development. Vygotsky's theory stated that "students learn through social interactions and their culture" (Woolfolk, 2004).

Problems

The difference between things as perceived and things as desired (Gause and Weinberg, 1989)

Problem Solving

It is a complex intellectual function that use "higher order cognitive process which requires the modulation and control of more routine or fundamental skills" (Goldstein and Levin, 1987). It is a process used to effectively and efficiently obtain the best value of an unknown or the best decision when method of solution is not obvious (Woods, et al., 1997). It is "ill-structured, workplace problems that have unclear goals and unstated constraints. It has multiple solutions and solution paths, without consensual agreement on the appropriate solutions. It involves multiple criteria for evaluating the solutions, possesses no explicit means for determining appropriate actions or relationships between concepts, rules, and principles to be used. It requires learners to make judgments and express personal opinions or beliefs about the problem" (Jonassen, Strobel, and Lee, 2006).

Problem Solving Processes

Steps required to successfully solve a given problem. In engineering, the common steps are problem identification, followed by problem analysis and synthesis and finally solution generation, and are iterative in nature (Phillips, 2008).

Problem Solving Elements

Important essentials for problem solvers to solve a given problems. The important essentials for good problem solvers are the understanding and the use of good problem solving processes in solving a given problem, self-directed learning, and regular reflections.

Problem Solving Assets

Resources someone acquired through good problem solving practices which are knowledge, confidence, and thinking/cognitive process. Adams (2008) defined it as a set of assets that a solver brings to bear when solving a problem.

Problem Solving Skills

Skills required in solving complex problems under certain condition, such as team-based problem solving requires team working skills, furthermore, solving complex problems call for strong resilience which requires motivation and learning strategies. The skills also consist of all elements of problem solving such as identifying, analyzing, synthesizing, generating solutions and reflecting. Mayer and Wittrock (2006) include meta-skill in the categorization such as knowledge of how to ask the right questions, self-directed learning and monitoring.

Cooperative Learning (CL)

CL is an “instructional approach in which students work in a team on a learning task structured to have the following features; (1) positive interdependence, (2) individual accountability, (3) face-to-face interaction, (4) appropriate use of interpersonal skills, and (5) regular self-assessment of team functioning” (Johnson, Johnson and Smith, 2006).

Problem-based Learning (PBL)

"Learning that results from the process of working towards the understanding and resolution of a problem (Barrows and Tamblyn, 1980). It is an instructional learner-centered approach that empowers learners to find information, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" (Savery, 2006). "Based on the principle of using problems as a starting point for the acquisition and integration of new knowledge, the method is designed to create learning through prior learning experience and to reinforce existing knowledge. It is based on constructivist values, where the curriculum moves from the whole to the part" (Finkle, 2000).

1.12 Conclusion

For a conclusion, let us revisit the thinking of John Dewey (1938b). His philosophy of education and theory of inquiry are very much relevant to engineering education particularly in teaching engineering students to become problem solvers. Dewey (1938b) argues that "facts are facts in the context of inquiry". The consequence of this is that the teaching facts outside the context of inquiry are unproductive. However, lecturers spend most of the time teaching facts outside the context of inquiry. Meanwhile, students spend much of their time memorizing facts, which they promptly forget after tests. "If the inquiry genuinely matters to students, they will seek out the facts and remember them long after the problem has been solved" (Mina, Omidvar, Knott, 2003). CPBL is a promising practice that will enhance engineers' problem solving skills and is aligned to the John Dewey theory of inquiry. To what extent is this claim true? This research investigates the claim. In doing so, it also investigates the reasons that allow this to happen.

This chapter started by establishing the research background. It highlighted the current technological growth and challenges, and the complexity of problems faced by today's and future engineering world that calls for the need to produce graduate engineers with sound professional skills, particularly problem solving. It is then followed by formation of research questions and objectives. Based upon several theories underpinning the study, the research conceptual framework was established. Significance of the study, scope of the study, and several important definitions used and applied in this research were presented here, in this chapter.

This thesis is divided into five chapters. Each chapter has been partitioned into several parts and sections, which has been carefully done so that it complements the flow of the dissertation as a whole. Chapter 1 is the present chapter which is the general introduction to the research. Chapter 2 will bring us to the illustration of several evidences based on meta-analysis. Chapter 3 details the design of the research. It covers all methods used to achieve the required results. Chapter 4 contains data analysis. It discusses all quantitative and qualitative data used in producing results. Chapter 5 discusses the results obtained from the analysis according to the finding in Chapter 4. It also forwards the conclusion of the study. It highlights the motive, the significances, and the limitations of the study. In Chapter 5, the thesis ends up with recommendations of the possible continuation of the research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews and elaborates the important topics outlined in Chapter 1. It covers the reviewing on the future of engineering education, issues related to problem solving skills as well as cooperative and problem solving teaching methods. This chapter starts by looking at the current engineering practices and engineering education as a whole. It follows with reviews on the challenges of today's world and the future demands. This is important for the research as it sets the direction and the context to the future requirements in engineering education. This is then followed by reviewing on the needs of the future engineers and their skills requirements. It ends by looking closely at the future of engineering education as reported in the literature. All these are elaborated in Section 2.2.

Section 2.3 discusses on the problem solving skills in engineering education which is mostly governed by findings from four prominent researchers in engineering problem solving, Jonassen (1997, 2000, 2004), Woods (2000, 2004), Phillips (2008) and Adams (2008). It starts with the awareness of the importance of acquiring problem solving skills among engineering graduates, followed by the conceptual and topology of problem solving, the problem solving processes and assets, instructional design for problem solving skills enhancement**,** and the problem solving and lessons for engineering educators.

The teaching and learning methods known as the Cooperative Learning (CL), Problem-based Learning (PBL) and Cooperative Problem-Based Learning (CPBL) in which the research on the enhancement of problem solving skills among engineering students is based upon, are critically reviewed in Section 2.4. This chapter ends by proposing a theoretical framework to enhance the problem solving skills.

2.2 Engineers and Engineering Education

The motivation to research in this particular area was mooted when there are concerns whether the current engineering education program is able to produce future engineers, and concerns about what are the skills required for engineers in order to face challenges of the future? These questions are discuss in the preceding section and is mainly based on reports below:

i. Phase I - Engineer of 2020: Visions of Engineering in the New Century (Wayne, 2004),
ii. Phase II - Educating the Engineer of 2020: Adapting Engineering Education to the New Century (Wayne, 2005),
iii. Educating Engineers for the 21st Century: The Industry View (Spinks, Silburn and Birchall, 2006), and
iv. Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research and Education (Duderstadt, 2008).

The Engineer of 2020 (Wayne, 2004; 2005) were the efforts of the American National Academy of Engineers (NAE) study conducted in two phases to stimulate change in engineering education. Educating Engineers for the 21st Century (Spinks, Silburn and Birchall, 2006) is a report of thorough investigation on UK undergraduate engineering education requirements in terms of the current and future needs of the engineering industry. It is a study carried out by Henley Management College for The Royal Academy of Engineering. Engineering for a Changing World is a report written by Duderstadt (2008), a president emeritus and university professor of science and engineering, University of Michigan. It is heavily influenced by a number of important latest studies; of particular note were the The Engineer of

2020 (Parts I and II) (Wayne, 2004; 2005), Engineering Research and America's Future (NAE, 2005); Rising Above the Gathering Storm (Augustine, 2005), the Federal Science and Technology Budget (COSEPUP, 2003), The Science and Engineering Workforce: Realizing America's Potential (NSB, 2003) and The Future of Engineering Education (Shuman, 2002).

2.2.1 Current Engineers and the Engineering Education

Engineering is a profession where the mathematical and natural sciences knowledge gained through learning and practicing activities is applied with judgment to develop ways, utilize the natural or man-made materials and the forces of nature's economically for the benefit of mankind (ABET, 2011). Engineers are qualified personnel who acquire and practice the above in the engineering discipline. Engineers are generally known as those who apply science and technology to help solve problems and meet the demands of the society. Their duties are to solve problems, generate ideas and build devices, systems and structures. They revolutionize the future. The intellectual activities of engineering are mainly based on identifying problems, analyzing, synthesizing, designing, constructing and innovating through the integration of knowledge and experience (IEA, 2009).

Most engineering education providers offer programs based on four major engineering areas that is civil, mechanical, electrical and chemical. However, other specialized areas like industrial, aerospace, agricultural, automotive, biomedical, computer, environmental, manufacturing, materials, metallurgical, mining, nuclear, petroleum, sanitary, system, and transportation are also growing up. Yet, after graduation, the graduate are more likely to work on either broad or specific roles and activities, such as product designer, manufacturing engineer, systems engineer, process engineer, research and development officer, construction engineer, project manager, operations engineer, testing engineer, sales and marketing engineer, manager, consultant, researcher and lecturer.

Engineering is also a learned profession, similar to law and medicine. This profession is governed by code of professional ethic and engineers must possess certain specific skills, which can only be acquired through formal educations and industrial practices. In order to be a professional engineer, one must pass the examinations conducted by professional bodies or organizations. However, the increasing demand by consumer in this new technological era coupled with the changing nature in engineering practices has created new dimensions and challenges in preparing graduates.

Traditionally in engineering practice, value is added through a vertical process, moving linearly through a sequence of activities such as research and development, product development, manufacturing, sales and marketing. It is essentially built around a strong educational foundation of science, mathematics, and engineering. But, today, the trend of global economy tends to function horizontally. The elements of adding value through products, systems and services disaggregated and then distributed throughout the world, to wherever and whoever can accomplish these tasks at highest quality. Traditional approach of creating large, multinational corporations both to capture market share and to protect intellectual assets and reduce financial risk is being challenged by very small, innovative and highly entrepreneurial enterprises (Duderstadt, 2008).

According to The Educating Engineers for the 21st century, two broad qualities targeted by engineering firms today are defining skills that are unique to an engineer and social and interpersonal skills. An engineer must have a strong fundamental engineering knowledge build solidly on mathematics, creativity, innovation and the ability to put the theories into application. In addition, they must be able to communicate and work as a team (Spinks, Silburn and Birchall, 2006).

With regard to the current engineering graduates' performance, Spinks, Silburn and Birchall (2006) indicated the difficulties of getting high quality engineering graduates from labour market. Engineering firms report that skills deficiencies have widely affected their activities which include delayed product developments, increased recruitment costs and restricted firm growth. Consequently, firms have resulted to a number of strategies. The strategies includes "up-skilling" by giving the engineers additional training, "in-skilling" by recruiting more engineers, and “out-skilling” by using third parties to commence skilled work. Moreover, this research also expressed concerns over the educational pipeline of prospective engineers from schools, universities and successively into engineering practices.

Doubts are expressed on the current educational system in which some theories thought in universities are never translated into reality. Furthermore, the current grading system is often a poor indicator of a graduate’s abilities. Based on the responses by the industry on five most important skills required for the current engineers, it reveals that six out of more than fifty different skills are the communications, technical ability, creativity and innovation, problem solving, analytical skills and people management. There are various comments on how well faculty members deliver the engineering courses and help students to develop these skills. In universities, project work is viewed as important in developing problem solving skills. However, in most cases, the projects given were limited and lack real issues of the working environment. Even though project work was universally seen as important, it needed more relevance then the usual determined structural problems. Another criticism within the assessment of universities is the stress put upon students on rote learning and memory. The worth of an engineer is not just determined just because one does not remember 100 equations (Spinks, Silburn and Birchall, 2006).

2.2.2 The Challenges of Today and Tomorrow

In the first phase of the Engineer 2020 (NAE, 2004), several provocative scenarios of engineering challenges have been discussed. The challenges of technology today all corresponds to technological developments such as biotechnology and information technology. From the social aspect, today’s engineers face challenges in growth of world population, health care and global economy acceleration (Refer to Table 2.1 and 2.2).

Future engineers will face challenges that are qualitatively similar to the present challenges. They will need to be prepared to find micro and macro solutions to problems in the ever changing world (Vest, 2008). Future engineers have to be able to anticipate every possible disaster and ensure that they are prepared for it. They have to design solutions that will reduce the possibility of disaster while simultaneously creating a comprehensive backup plan (NAE, 2005).

In the planning processes, Duderstadt (2008) has adopted the approach of environmental scanning as a series of challenges of both the world and the engineering. The study has divided these challenges into two categories, the challenges and the grand challenges. The difference between the two is the global commitment to the challenges, for the second can only be addressed by new technologies implemented on a global scale (Duderstadt, 2008). Table 2.1 and Table 2.2 summarize all the challenges.

Table 2.1: The challenges

The Challenges	From 20th to 21st Century
Knowledge Economy	Products to ideas Manufacturing to services Public policy to markets Monopoly to innovation
Globalization	A global economy Rich vs. poor Global resources (oil, water, …) Global sustainability
Demographics	Aging societies The global teenager Population mobility Cultural diversity
Technological Change	Exponentiation technologies Info-bio-nano convergence Disruptive technologies Technology to social change
Technological Innovation	Commodities to innovation Analysis to synthesis Reductionism to consilience Hierarchy to networks

Table 2.2: The grand challenges

The Grand Challenges	
Global Sustainability	Destruction of forests, wetlands, and other natural habitats Global warming Ballooning global population
Energy	Unsustainable fossil fuel Sustainable energy technologies Alternative energy technologies Energy infrastructure
Global Poverty and Health	Green revolution 1/6 population - extreme poverty Globalization
Infrastructure	Aging infrastructure Urbanization Manufacturing to knowledge services Systems integration

2.2.3 Future Engineers and the Skills Requirement

There is a need to make revolutionary changes in the engineering profession due to external factors such as globalization and exponentiation technologies. Tomorrows' engineers need the capacity to function globally using current technologies and economy. As mentioned by Kennedy (2006), "We need engineers who know something about working with others – not just teamwork, but a basic understanding that our culture is not the only one around! We must prepare engineers to be global citizens. They must learn to translate ideas and plans into reality for cultures that may not look, sound, or dress the way we do. Unless we can do that, a large part of our engineering business will soon leave our shores". Tomorrow's engineers need this global awareness. They require the ability to perform in the context of global perspective engineering practice, not only having a deep understanding of global markets and organizations, but also the capability to work in diverse multidisciplinary teams while demonstrating flexibility to address the challenges faced in the rapidly progressing world. This multidisciplinary collaboration across multiple fields represents one of the multidimensional challenges which future engineers have to face (Wayne, 2004).

Due to exponentiation technologies, Duderstadt (2008) emphasized the need of the future engineers to innovate, which is strongly dependent upon their capacity to synthesize and create. He also emphasized the essential competency in integrating knowledge across an increasingly broad intellectual span - from the natural sciences with that of the social sciences and humanities. Focusing on one or even several of the traditional technical disciplines of engineering will simply not be sufficient to address the complexity of the needs of tomorrow's society. Engineering is a field where knowledge is ever expanding. New tools are always developed to sustain this exponential knowledge growth. Future engineers will have to adapt with this change. They will have to make use of new tools, apply unprecedented knowledge, and more importantly, know how to cooperate with diverse team of people in order to find solution to novel problems. It will be essential for them to address increasingly convoluted problems in order to cope with the changes in nature and scale of the future engineering field.

In the Engineers 2020 (Wayne, 2004) the NAE proposed the future of engineering to be established as a true learned profession similar to law and medicine. They also aim to attain a more diverse engineering participant. This includes increasing the roles and types of engineers and varying the programs engaged in preparing them for professional practice. To better understand the skills and competencies necessary for tomorrow engineers, Bordogna (1995) suggests the possible careers for engineers in the field of "sustainable development, energy/ materials efficiency, life cycle/infrastructure creation and renewal, micro/nanotechnology/micro-electro mechanical systems, mega systems, smart systems, multimedia and computer-communications, living systems engineering, management of technological innovation and enterprise transformation". According to the NAE report (Wayne, 2004), the need of synergy between technical and social systems will also change the way engineering is applied. For example, engineering will help to establish sustainable transportation systems, efficient methods for energy and power delivery, comprehensive telecommunications networks, and cost-effective methods for delivering adequate food and safe drinking water. In order to accomplish engineering's potential to create a better world; it will need to increase its influence on thought patterns and political impact. The engineers of tomorrow will directly involve in real life arenas such as political and community arenas. They will need to profoundly understand their position, their workforce constrains, and the training necessities for dealing with customers and the public.

The first report of Engineers 2020 (Wayne, 2004) offers a glimpse of what engineers are going to, and need to be able to do in the future, thus will be used as a guidance to prepare today and tomorrow engineers. This report specifically points out that engineers must be able to function as team members. While stressing that an ability to communicate is an attribute of the engineer of 2020, 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”. The report lists the crucial qualities of engineers that will provide the scaffolding for the excellence of engineering profession in the future. They are as follows:

i. Possess strong analytical skills – Uses the scientific and mathematics principals along with domain and discovery design
ii. Exhibit practical ingenuity – Have the ability to plan combine and adapt. By combining science and practical ingenuity, problems and solutions can be found
iii. Creativity – Some problems needs the combination of a wider interdisciplinary knowledge and a focus on systematic constructs and outcomes
iv. Require good communication – Engineers are required to communicate with various interdisciplinary teams, public officials and customers
v. Understand the principles of leadership – Acknowledge that public service is crucial and have a place in society
vi. Master the principles of business and management
vii. Understand the principles of leadership
viii. Righteous
ix. Professional demeanor.
x. Dynamic, agility and flexible – since the technology change so quickly and the continuous change of social-political-economy, engineers need the ability to learn new things quickly, and the ability to apply knowledge to new problems and new context.

xi. Lifelong learners – the engineers need this not only because of rapid technological advancement, but also because the career trajectories of engineers will take on many directions.

The research by Spinks, Silburn, and Birchall (2006) finds that the pace of industrial evolution is anticipated to increase drastically in both the technological and non-technological domains. These include an increased need for firms to focus on solving customer problems; a growing requirement to provide system solutions to those problems; and the increasing complexity of the management task. This management complexity is paralleled by the advancement of technological complexity and interdependence at all stages. In terms of future skills needed, there is strong evidence that the top priorities will be practical application, theoretical understanding, creative and innovative, and team-working abilities. The research depicts roles of future engineer. Firstly, engineers have a role as a specialist. Graduate engineers must have technical expertise that is recognized worldwide. Secondly, they are integrators. Graduate engineers can operate and manage across frontiers, whether it is technical or organizational and still maintain a complex professional atmosphere. Thirdly, engineers are the agents of revolution. Graduate have a crucial role in supplying ideas, innovations and leadership which are critical in shaping a successful future. These skills and roles required of future engineers in such conditions are profoundly different than those imparted by the typical engineering curriculum.

2.2.4 The Future Needs of Engineering Education

The engineering skills requirements mentioned in the previous section call for a change in traditional engineering education approach. As recommended by the National Sciences Foundation of the USA (NSB, 2007), the traditional lecture-laboratory approach should move towards a more active learning. It is now essential for engineering faculty to deploy a discovery-oriented learning atmosphere to take advantage of the current technologies. But, these matters are not new, nor are they unique to engineering education. Scientists in the education and psychology field have long since realized that the most effective learning occurs through discovery and application, not just through theories and mere reading. There are plenty evidences reported that most students learn best through "constructionist" learning (see Dewey, 1938a; Piaget, 1954; and Papert, 1993). As reported by Duderstads (2008), looking back through history, the last major change which is undergone by engineering education happens post-World War II. The earlier undergraduate curriculum was more practical-based, such as the mastery of practical engineering tools. Then, it was changed to be built upon a strong scientific base, adopting both the pedagogical methods and the faculty reward structure of the sciences. Nowadays, as stated by Lumancusa et al., (2008), many believe that we need to take the previous practice of learning and inculcate it into the current curriculum. Usually, discovery-based or constructionist learning in engineering education might be more valuable to experiential approach. This includes on-campus activities such as design or system integration instead of the usual classrooms or laboratories, supported by faculty with experience and actively participating in engineering practice. In a sense, this would involve "turning the curriculum inside out, putting engineering experience at the core and wrapping about it the engineering sciences enabling problem solving" (Jamieson, 2007). In today's scenario, this is crucial as urged by Brown (2005), educators should strive to teach engineering students "how to do", not just "how to be" by creating immersive experiences for them.

New educational pedagogies such as the inductive teaching methods (Prince and Felder, 2006) are corresponding to the active learners of today. Students' today tend to construct their own knowledge structures and learning environments through interaction and collaboration. On several technology-rich campuses, the growth of peer-to-peer learning and virtual world (ex: massive multi-layer gaming and simulations) are replacing faculty lectures as the dominant educational process. Some cognitive scientists (such as Bruner, 1990) even conclude to turn the students loose by letting them define their own learning environment. This may perhaps be the best approach in today's technology-rich environments. As students are becoming active learners, the demand for responsibility of their own learning experiences and outcomes sky rockets. The new paradigms today render the old stereotype of the word "student" null. Students will no longer be considered as a "sponge", absorbing contents delivered by the teachers. Rather, the clients of the 21st century should be considered as active learners. In relation, the role of lecturers as one who develops and conveys knowledge to a vast population of passive students becomes obsolete. A faculty member of a certain expertise is usually expected to determine the key points, organize and present the material, usually in lecture formats. This no longer applies to the paradigm of today. The faculty members should now be more responsible to guiding and nurturing active learners rather than to identifying and presenting contents. At which, the educators of today are expected to manage, coach, motivate and inspire the students. Future engineering education will be pressured to change from faculty-centered institutions (in which the faculty decides the material, the targeted individuals, the way they convey points, the place and the time for each and every lesson) to into the exact opposite, learner-centered institutions where students have more options and control of how, when, where and what they learn.

The first report of The Engineers of 2020 (Wayne, 2004) discusses the implication on both the technology and social context for engineering education. The implication of technology in engineering education can be summarizes as follows;

i. The technology expansion – knowledge of new scientific and technological discoveries continues to expand and this demands more specialization. Engineering education must avoid "teaching more and more, about less and less, until it teaches everything about nothing",
ii. The technological acceleration – scientific and engineering knowledge doubles every decade (Wright, 1999). Engineers have to accept the responsibility for their self-continual reeducation and engineering schools have to prepare students to do so by actually teaching them how to learn.

Whereas, the implication of social context can be summarizes as follows;

i. The aging population – causes decrease enrollment at many engineering schools. The engineering school may have to create new-less rigorous engineering programs to attract a new pool of students.
ii. The global economy – enhanced productivity by involving international partnerships.

iii. Teamwork, communication and public policy – can engineering education step up to the challenge of providing a broader education to engineering students?

The second report of The Engineers of 2020 (Wayne, 2005) was a recommendation of possible changes in engineering education to address these futures. Among the recommendations were the following:

i. Universities should manipulate the flexibility in the ABET accreditation criteria in making innovative curricula.
ii. In addition to producing engineers who have been taught the advances in core knowledge and are able to define and solve problems, universities must teach students how to learn for a lifelong period.
iii. Engineering educators should use case studies of engineering successes and failures as a learning tool.

To address the above issues, Vest (2006) envisaged that tomorrow's engineers need to be able to bring into existence a set of new and possibly revolutionary tools and technologies. The embodiment of the core knowledge and skills will be of importance, supporting effective engineering education and realizing a sense of engineering professionalism in the new century. For profession and engineering educationists, it is essential that the students receive the core knowledge advances in information technology, biotechnology, nano science, photonics, and such and also other yet to be discovered areas in order for the future engineers to further leverage them to achieve interdisciplinary solutions to engineering problems in their engineering practice. With the fast paced nature of the modern world, the engineers, more than ever before, must embrace continual education as a career progression strategy.

The second report of the Engineers of 2020 (Wayne, 2005) provides engineering educators way to accomplish the objective. It is proposed that there is a need to look at engineering problems in "systems perspective" and initiatives the need to "pursue collaborations of multi-disciplinary teams of technical experts". Reform of engineering education must account for the systematic nature of engineering. Since engineering is a complex system, previous reform attempts seems to fail because the changes are made in 'silos' or only through one part of the system while ignoring the others. While pointing out the need to treat the profession of engineering as a system, another important element of engineering is the "engagement of the engineer and professional from different disciplines in team-based problem-solving processes"

Table 2.3 summarizes the discussion in this section. It highlighted the challengers of the 21st century, the attributes of effective engineers and the desired characteristic of engineering education in the 21st century.

Table 2.3: The engineers and engineering education of the 21st century

Challenges of the 21st Century	**Attributes of Effective Engineers**	**Desired Characteristics of Engineering Education**
• knowledge economy • globalization • demographics, • technological change • technological innovation • global sustainability • energy • global poverty and health • infrastructure	• Critical • Practical • Creative • Communication skills • Leadership skills • Team working skills • Professional • Dynamic, agility, resilience and flexible • Lifelong learners • Function in global economy • Business and management skills • Ethics	• Learner-centered • Discovery-based or constructivist learning • Systems perspective • Avoid content orientation • Learn how to learn • inquiry-based scientific methods • Team-based problem solving • Prepare engineers into the global economy

2.3 Problem Solving Skills in Engineering Education

Study conducted through the collaboration of three UK universities, the Institute of Engineering and Technology (IET) and the Higher Education Funding Council of England (HEFCE) summed up that 77% of employers request graduates who is able to self-learn and 74% of employer needed problem solvers. A working group lead by Sir David Brown (ex-chairman of Motorola and IET president) that comprised of a balanced membership of academics and industries discovered that most employees search for graduates with key skills. They desire for these skills to be adapted into the engineering degree courses and assessments. Rather than focusing on the cognitive knowledge possessed by the students, employees show distress over the lack of key skills of the graduates. The highest of all these skills are problem solving, followed by computer literacy, interpersonal skills, team working skills, numeracy skills, communication skills and time management skills (IET, 2008).

In The Global Engineers, Katehi (2005) informs that the future engineering curriculum to be constructed not around teaching the available knowledge, but should be around developing skills. They must cogitate about developing students' analytical thinking skills, problem solving skills and design skills.

Mina, Omidvar, and Knott (2003) in their paper mention about the difficulties of having undergraduate programs which last within the periods of four-to-five years, but yet expecting to produce well-rounded and creative engineers. Apart from the require core engineering courses, social sciences and general education courses are introduced to ensure the students are able to adapt to their situations and use systematic thinking process at their work place. The aim of engineering programs is to produce competent engineers with skills which will be of value in various situations. Many engineering instructors realize that many students do not care about being a well-rounded engineers thus not attending to the details. Moreover, the teaching process nowadays focuses on obtaining solutions. The answer is the main aim, not the quality and depth of the thinking process. From the students' point of view, they will not suffer immediate consequences and the employees might accept blind followers and spare time and resources in order to re-educate them. This situation poses as a serious problem and arouses complicating challenges to the instructors. Industries complain that a large number of engineering program graduates lack the characteristics of a self-learner. Most of the students are capable but are deprived of systematic training in thinking about problems. They are not able to adjust to the changes in technology, nor can they help the process of change. This calls the need for effective solutions.

2.3.1 The Conceptual and Topology of Problem Solving

Problems are normally associated by problem domain, problem type, problem solving process and solution. The problem domain comprises of the content (concepts, rules, and principles) that describes the problem elements. The problem type describes the combination of concepts, rules and procedures for acting to find solution to the problem. The problem solving process consists of problem identification, problem analysis and synthesis and solution generation. Solution is the final result to the problem. According to Jonassen, (1997) there are two critical attributes of a problem "First, it is an unknown entity in some situation. And second, finding and solving for the unknown must have some social, cultural or intellectual value".

Problem solving is a process used to find the best solution to an unfamiliar problem, or making decision subject to some restrictions (Woods et al., 1997; Jonassen, 2006). It is any "goal-oriented" sequence of cognitive processes. These operations have two critical characteristics;

i. it requires the mental representation of the situation
ii. it necessitates some activity-based operations of the problem.

According to Sweller (1988), "The problem-solving process depends upon the problem solver's understanding and representations of the problem. With practice over time, problem solvers construct richer problem representations.

Experts differ from novices because their problem schemas better enable them to recognize a problem situation as belonging to a certain class of problem. Novices, on the other hand, possess deficient problem schemas and so are not able to recognize problem states as well, so they have to rely on generalized problem solving strategies"

For a problem solver, the aim is to achieve the solution. The solution may be convergent or divergent. Convergent means there is a single, known solution, while convergent means there could be one of more acceptable solutions to the problem. Problems comes in many forms, well-defined or ill-defines, complex or simple, familiar of unfamiliar, short term or long term, and discovered or presented (Arlin, 1989)

At its simplest form, problems can be separated into well-structured and ill-structured (Simon, 1973). The problems which are usually found in school are well-structured problems. The well-structured problems are problems that have correct solutions and are determined by preferred paths based on certain rules and principals. When the students learn to solve these kinds of problems in engineering education, they learn to translate the relationships about unknowns into equations, solve the related equations and check the values to ensure it satisfies the original problem. This one-dimensional process demands the memorization of a procedure, practiced, and accustom one's self to the problem. It also stresses the answer over the meanings. The skills honed from solving problems of this sort will be applicable in similar types of problems. However, the effects of these types of well-structured problems are that they limit the relevance and transferability of problems in everyday contexts.

Ill-structured problems are problems at which one or more aspect of the given situation is not clear. These problems are not well defined and have various solutions and paths in order to obtain them. Usually, no common agreement on the approximate solution is obtained. Multiple criteria for evaluating solutions without explicit means for determining appropriate actions between concepts, rules, and principles to be used (Chi and Glaser, 1981). Thus, learners are required to give personal judgments or beliefs regarding the problem and defend them. These are the kind of problem one would encounter in everyday life. Hence, it is much more meaningful and interesting to the learners, who are required to define the problem and determine what information and skills are needed to solve it.

Simon (1973) discussed in detail about the boundary between well-structured and ill-structured problems. In the laymen term, the well-structured is the exercise solving and the ill-structured is the problem solving. This term remain till today and is used in this research. Table 2.4 below summarized the differences. The enhancement of problem solving skills in this research meant literary as problem solving defined here.

Table 2.4: Difference between problem and exercise solving

Problem Solving	Exercise Solving
- Process to obtain best answer to an unknown, subject to constraints	- Process obtain the one and only answer
- Ill defined	- Well defined
- Brand-new	- Encounter similar problem before
- No explicit statement	- Explicit, hints given
- More than one approach	- Usually one approach to one answer
- Algorithm to solve unclear	- Recall familiar solutions – usual method
- Integration of knowledge	- Subject by subject
- Strong skills of presenting results	- Presentation skills not required

2.3.2 The Engineering Problem Solving Process

In general, engineering problem solving process can be divided into three phases; the definition phase, the strategy phase and the solution phase (Phillips, 2008). 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 collecting, testing, analyzing, and synthesizing 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 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 to include a series of actions as described above. Different researchers and engineering educators frequently refer to similar information through differences in terminology, sequence, and detail. One consistent feature of engineering problem solving is that of iteration. At the same time, the foundational phases of problem solving serve as critical anchors for more detailed activities required for effective solutions. Figure 2.1 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. As shown in the figure, the process is iterative in nature. This iterative nature is one of the key characteristics of engineering problem solving.

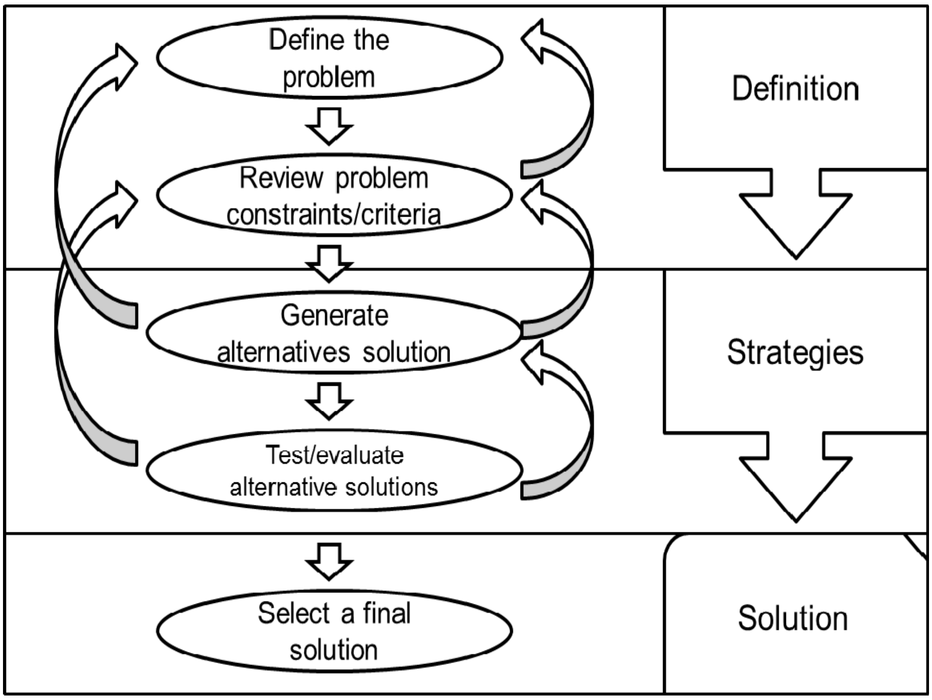


Figure 2.1: The engineering problem solving process (Phillip, 2008)

2.3.3 The Problem Solving Assets

Three components of problem solving assets have been identified and various schemes were used to categorize these components. Originally, Mayer and Wittrock (2006) divide the components into two, which are knowledge and process. Adams (2007) made an alteration to the original. As shown in Table 2.5 (Adam, 2008), beliefs and expectations have been taken out of the knowledge section and places alongside the motivation in an additional category. In the division, Table 2.6 divides the assets into three, and also shows how each division interacts with others. The divisions are created based on what the solvers bring with them (which is the knowledge) and what the solvers do (which is the processes, with beliefs, motivations and expectations are in between).

Beliefs, motivation and expectations are what a person brings and have various senses than other knowledge pieces. Mayer's (1998) structure, "knowledge and processes" or "knowing and doing" are important to problem solving. The essential assets to solve any type of problems are covered in the structure. Division also helps to clarify things such as meta-cognitive knowledge and meta-processing which frequently get grouped together even though they have different effects on problem solving.

Table 2.5: Knowledge and Cognitive Processes Involved in Problem Solving (Adams, 2008)

Knowledge – have		Processes – do
Facts and concepts Strategic Procedural	Beliefs, Expectations and Motivation	Representation/Qualitative Analysis Planning/Monitoring & Assessing Executing Meta-processing

The table shows the connections between the specific types of knowledge the solvers apply while encountering with various processes:

- when formulating problem representation, they use facts and concepts which they believe relate to the problem;
- while planning and monitoring they used problem solving strategies; and
- when the plan is carried out, the procedural knowledge that they have learned applies to the topic.

Beliefs, motivations and expectations shape a problem solver's cognitive processes. Thus, it is between the knowledge and processes. They also determine how and which knowledge items shall be used.

Knowledge comprises of factual knowledge, semantic knowledge, procedural knowledge and strategic knowledge. It is something which is owned. Beliefs and expectations include various ideas about the things that the students expect and what they believe is important or useful about them (including meta-cognitive knowledge) and about the problem. There are many different reasons of motivation. It could be internally, externally, weakly or negatively motivated. Cognitive processing is something that is "done" while engaged in productive problem solving. For examples, building a model of problem space, planning, monitoring, and executing (Adams, 2008).

2.3.4 Novices versus Experts Problem Solvers

When considering maturity in thinking and meta-cognitive activities on problem solving, several approaches have been suggested. Among them are Bloom's taxonomy (Bloom et.al., 1958), Piaget's assimilation versus accommodation (Piaget, 1964), Chi's experts versus novices (Chi, Feltovich, and Glaser, 1981), and SOLO taxonomy (Biggs and Tang, 2007).

In the Bloom's et al., (1956) taxonomy of cognitive domain, Bloom and his associates identified six levels of learning. The level at its lowest is the knowledge or recognition of facts, followed by comprehension, application, analysis, synthesis and evaluation. Colleagues of Bloom's, Anderson and Krathwohl (2001), revised the taxonomy, reorganizing some of the classifications and turns the nouns of the taxonomy into verbs with remembering at its lowest level, then followed understanding, applying, analyzing, evaluating and creating. Novice problem solvers usually use remembering and understanding, while experts usually exercise the top three levels of the taxonomy.

Piaget distinguished "assimilation" and "accommodation" as the two main learning activities. Assimilation is associated with novices, how the problem solvers deal with new knowledge. Likewise, accommodation is associated to the experts; describing how obtainable knowledge are organized. Xu and Rajlich (2005) further separate assimilation into two other activities: "absorption" and "denial". Absorption takes place when the learners accept new facts and denial is when the facts obtained do not fit in with the present knowledge resulting in rejection. Accommodation is also separated into two activities which are "reorganization" and "expulsion". At the time which knowledge is reorganized for aid of absorption in the future, "reorganization" takes place. "Expulsion" is when some of the knowledge is no longer valid or provably incorrect and the problem solvers reject it.

Chi, Feltovich, and Glaser (1981) made an arrangement and representation of problems from the views of both the experts and the novices. They examined the difference of novice and experts in solving problems. They contended that the arrangement by a novice was based on "naïve" representation, while a more "scientific" representation based on principals and concepts was constructed by the experts..

Biggs and Tang (2007) classified five cognitive levels in what is known as the SOLO taxonomy of the cognitive domain. 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 three levels of problem solvers as surface learners and the top two as deep learners.

2.3.5 Instructional Design for Problem Solving

The IDEAL problem solver (Bransford and Stein, 1984) is a well-known model. It involves identifying the potential problem, defining and representing the posed problem, examining possible strategies, acting on them, and revising and evaluating the impact of those activities Gick (1986). These and other problem solving models (Greeno, 1978) are synthesized into a simplified schematic as shown in Figure 2.2.

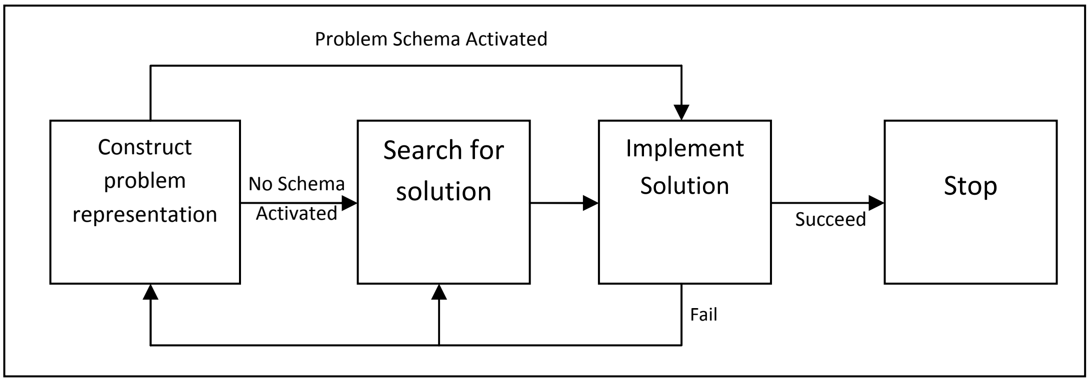


Figure 2.2: Schematic diagram of well-structured problem solving process (Gick, 1986)

One solution after another is tested by the problem solver by generating possible solutions to the problem which are implemented and tested. The process continues until a successful solution is obtained. No emphasis is made to finding more than one applicable solution, so when a successful solution is obtained, the process is concluded. Problem solving tasks which are presented results in the problem representation constructed by individuals. It does not emerge from the context or one which they make up themselves (Jonneson, 1997).

The ill-structured problem solving process consists any mixture of a general problem solving, which sometimes working on some well-structured sub-problem. It continuously modifies the problem space with new constraints, new sub-objective and new generations of alternatives. It is able of interrupting the ongoing processes of problem solving system (Simon, 1973). The schematic diagram for ill-structured problem is shown in Figure 2.3. Note that the well-structured and ill-structured problems are not really separate entities; rather they signify points on a continuum (Reitman, 1965).

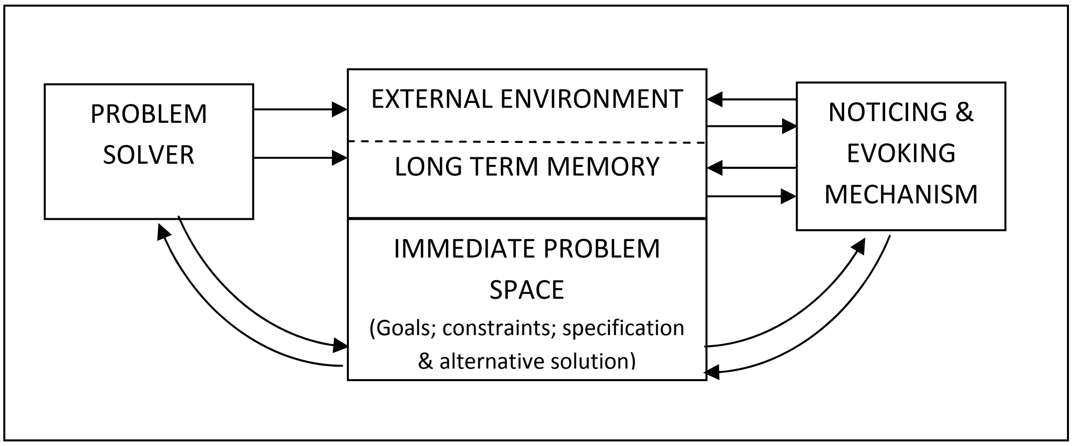


Figure 2.3: Schematic diagram of ill-structured problem solving process (Simon, 1973)

The process of designing and developing ill-structured problem solving instructions needs the cooperation of the designer with experts and experienced practitioners. The steps taken in the design are as suggested by Jonassen, (1997):

i. **Articulate Problem Context** - As ill-structured problems are context-dependant, it is first necessary to understand the context of the problem. Therefore, a context analysis needs to be conducted by asking questions such as: What is the nature of the domain, the constraints imposed, the kinds of problems solved, and the contextual constraints that affect problems? Designers need to generate an inventory of all of the domain knowledge - not as a list of concepts, rules, and principles as with well-structured problems, but rather information about the context in which the problem is naturally embedded.

ii. **Introduce Problem Constraints** - Contextualized problems should be included in the cases introduced. Thus, designers should develop real-world problems which are challenging yet solvable. An abundance of smaller problems usually enables the problem solvers to handle the cases better than less, but larger cases. So avoid stuffing every single problem aspect in a large case. Perform casual analysis of the cases to confirm that the problem solvers are focusing on the actual problem.

iii. **Locate, Select, and Develop Cases for Learners** - Among the most powerful resources are stories that relate the problem. It is important that it represents real and divergent perspectives. Additional evidence, in the form of technical reports, videos and case histories should be included and made available to learners in a simple way. It is reasonable for expect learners to search for some of the information to scaffold their information collection.

iv. **Support Knowledge Base Construction** - Ill-structured problems are dialectical in nature, where two or more opposing conceptualizations of the problem are used to support different arguments with opposing assumptions. It is important that learners be able to articulate the assumptions in support of argument for whatever solution they recommend. The argument will provide the best evidence for knowledge that they have acquired. Modeling argumentation can also be scaffold by providing some related information. The arguments that are developed can provide a valuable assessment of the learner's problem-solving ability.

v. **Support Argument Construction** - Learners should be able to articulate contradictory assumptions in support of arguments for whatever solution that they recommend. The argument will provide the best evidence for knowledge that they have acquired. Developing convincing arguments to support thinking engages not only cognition and meta-cognition of the processes used to solve the problem, but also epistemic cognition of the epistemic nature of the process and the truth or value of different solutions.

vi. **Assess Problem Solutions** - Evaluating learners' solutions must consider process and product criteria. Solutions can only be assessed in terms of their viability. The questions that are most interested in answering are: Was the problem solved? Was it solved within the constraints? Can the learners articulate the causal relations implied? Can they explain why and how the problem was solved or why it was not solved by their solution?

2.3.5.1 McMaster Problem Solving (MPS)

Woods et al. (1997) conducted 4 research projects in problem solving since 1972. The findings of his 25-years of research in problem solving projects are summarized as follows:

i. Although the instructor was doing excellent and conscientious job of showing their approach to problem solving by worked problems, supplied sample solutions, and showed a variety of problem solving heuristic; students were unable to recognize, transfer or apply the skills.

ii. Students were tested on their comprehension of the subject knowledge. Woods found that they knew the subject knowledge, but they could not solve homework problems. Woods called the general, content-independent, missing skill "problem solving". The same finding had been reported elsewhere (Van, 1979).

iii. Despite individual professors' dedication and efforts to develop problem solving skill, "general problem solving skill" was not developed in the four-years of undergraduate program. Graduates showing the same ability that they had when they started the program.

iv. The workshops-style intervention made a difference. The students' confidence and skills improved when compared with performance of students who did not experience these workshops.

Woods et al., (1997) concluded from his findings that there is an identified, subject independent skill named problem solving which student will never develop by receiving lectures on how to solve problems, using open-ended problems, given sample solutions or having colleagues show their problem solving throughout a four-year program. To improve students' problem solving skills, problem-solving "workshops" seem to have the potential. In doing so, he introduced the McMaster Problem Solving (MPS) program.

The MPS is a stand-alone program planned on enhancing skills for problem solving. Woods identified 37 separated skills:

- 4 self-management skills
- 14 personal well defined problem solving abilities
- 5 solving ill-structured problems
- 7 interpersonal and group skills;
- 2 self-assessment
- 1 change management; and
- 4 lifetime learning skills.

The program was given 120 contact hours to develop the skills. For example, learning skills required 2 contact hours of workshop and 1 contact hour of note taking, time management required 2 to 4 contact hours. However, to develop all the 37 skills required 200 contact hours.

The workshop-style program has four different phases. The first phase, which is in the first semester of the second year; focus on nurturing solving skills involving well-defined, normal homework problems. The next phase is conducted during the students' first semester in the third year. Additional practices are given to enable them to apply these skills. The third phase comes shortly after in the second semester of the same year. In this phase, skills related to team problem solving are added. The fourth and final phase is in the students' final year. The skills demanded for open-ended problem solving and also the long term lifetime learning is introduced in this phase.

To evaluate the skills, the program used summative, formative and self-assessments. Summative assessment consisted of two three-hour examination and tests and examination for process skills (TEPS). For formative assessment, students are asked to write journals for every unit and to go through two personal interviews.

The experiment's main concern was on transferable skills. According to some arguments, students that experience a separate processing skills course that uses context-independent material will be unable to relate to the skills when used in a new context (Perkins and Salomon, 1989; and Woods et al., 1997). When a stand-alone course is thought, it does not improve the transferability of the skills. Woods argued that there are many obstacles to overcome in developing a student's skills when new subject knowledge is taught. He found that these skills are best developed through a three-stage process: (1) build; (2) bridge; (3) extend. During the build stage, students are asked to assess the degree which their skills have developed during the context-independent parts of the workshop. In the bridge stage, they reflect on the task elements of the workshop, which include subject rich activities. For the extend stage, students reflect on the use of the skills in their academic course and daily life. These stages are crucial for the program's success.

For future development, Woods et al., (1997) suggested that researchers identify the specific differences that have potentials to relate with the kind of cognitive and affective processes. He also suggested researches to design the instructional practices that support learning for each type of the problem. Another suggestion was the use of "designed differences instructional models" – if any, to create problem solving guidelines and to evaluate individual instructional components' effectiveness for learning to solve problems and subsequently transfer these skills to other problems.

2.3.6 Problem Solving and Lessons for Engineering Educators.

Psychologist and educators consider problem solving as an essential outcome in education. Despite this fact, the importance of problem solving skills had never been well expressed in any instructional design literature. It was not even mentioned in myriads of instructional design textbooks. Apart from Jonassen's (2004), the only instructional design text that address problem solving systematically was written by Van (1997). The text describes the usage of complex cognitive processes which are required in solving problems. However, the text's analysis is based on traditional hierarchal task decomposition which, for Jonassen (2006), is inadequate to analyse a spectrum of problem solving outcomes. The way Van (1997) treats each problem is similar. According to Gagne (1980), it is inappropriate to assume that different learning outcomes need different learning conditions. To him, different learning outcomes can have similar leaning conditions. However, if problem solving is regarded as a different learning outcome, this statement would be awkward. Problems are not always similar, thus the teaching method of problem solving skills cannot be similar to the teaching methods of component skills. As suggested by Mayer (1998), in order to support problem solving outcomes, the instructions should differ from rule or concept learning. It can also be assumed that learners will be able to solve a problem by identifying concepts, rules and principals that relates to the problem.

According to contemporary learning theories, problem solving is the pinnacle of a practice. Current concepts of student centred learning, such as open-ended learning (Hannafin et al., 1994; Land and Hannafin, 1996), goal-based scenarios (Schank et al., 1993; 1994), and problem-based learning (Barrows and Tamblyn, 1980; Barrows, 1986; Woods, 2000; Tan, 2004) concentrate on problem solving outcomes. These concepts tend to provide students with instructional strategies which include authentic cases, simulations, modelling, coaching, and scaffolding. The instructional strategies function as a support to the problem solving outcomes but insufficiently analyse the nature of the problems

In reality, engineers functions as problem solvers. They are employed, retained and salaried to solve problems. Therefore, it is vital for engineering students to be exposed to ill-structured (workplace) problems. Workplace problems are not parallel to problems often given to students in classrooms. The nature of workplace problems are commonly complex and ill-defines. This happens because of conflicting goals, multiple methods in solving the problem, unexpected problems or solutions, and various form of problem representation. Consequently, the ability to solve common classroom problems does not actually ensure the success of a student in solving actual workplace problems (Jonesson, Strobel and Lee, 2006).

Problems that are often encountered in engineering education programs are well structured. One of its characteristics is that it can be solved by applying an ideal solution method. The problems only apply a limited number of common rules that are organized predictively (Jonassen, 1997). When facing with a well-structured problem, students will only need to translate the unknown relationships into equations, solve the equations and validate that the values satisfy the problem. This is a linear process in which students memorize the procedures and habituate it. This process puts and emphasis on getting answers over making meaning. In the end, it develops students who are contented with superficial engineering knowledge rather than understanding it profoundly.

According to Jonassen (2002), for students to solve ill-structured problems, they must have sufficient conceptual framework. Ill-structured problems are defined ambiguously, with indistinct aims and constraints. The problems possess a multitude of solutions and solution paths with no distinct consensus on the proper solution and no obvious method of defining proper actions or connections among principles that are used. In order to evaluate ill-structured problems, students will have to observe the problems thoroughly from across multiple criteria. Finding the solutions to the problems require learners to make decisions and express and defend their opinions. Educators once believed that the knowledge to solve well-structured problems can be transferred and used in solving ill-structured problems. Yet, as some recent research explicitly shown, knowledge to solve well-structured problems is not readily transferrable to solve ill-structured problems. In other words, the ability to solve well-structured problems, which is developed in the current engineering courses, would not enable graduates to solve complex, ill-structured workplace problems.

Jonassen, Strobel and Lee (2006) had made a research that attempts to recognize the characteristics of workplace problems and to convey the activities and limitations that make the workplace problems to be so ill-structured. The results obtained from the research are used in designing genuine problem solving experience for engineering students. To supply a different viewpoint on the stories told by engineers, a qualitative analysis that applies grounded theory approach was done. Appendix A summarized the primary themes that emerged during the qualitative analysis. Engineering curricula should engage students with a wide spectrum of problems. Although educators often appeal to design problems which most practicing engineers will face, other problems that will help enhance students' cognitive abilities are also essential.

One of a promising ways to enhance problem solving skills among engineering students is to implement PBL (Duderstadt, 2008). However, converting to PBL requires systematic transformation of the academic curricula, or in the very least, an entire course. Although the method is believed to be successful in developing students' problem solving skills, most lecturers are not willing to put that much time and effort into innovating the present curricula. Furthermore, even if such commitment is possible, the PBL programs will face interminable challenge in constructing genuine, real life problems. In order to overcome this challenge, the programs must apply a systematic approach in identifying and responding to the current workplace problems. Although PBL is regarded as one of the most important pedagogical improvement today as reported by Prince and Felder (2006); most PBL classes are still unable to sufficiently accommodate workplace problems' nature inside the classroom. Strobel and Barneveld (2009) suggested that if the purpose of engineering education is to prepare future engineers for their workplace, PBL classes should strive consistently to resolve the convolutions and uncertainties of workplace problems during the course. Educators who are interested in problem solving but have no support in implementing the program, can, with minimal support, plan and apply PBL environments.

Problem solving involves higher-order cognitive skills and is among the most authentic, useful, and crucial skills that learners can develop (Jonassen, 1997). With this regards, Mina, Omidvar and Knott (2003) proposed to look at the problem from the lens of John Dewey. She found that the objective of engineering education program is parallel to John Dewey's own educational understanding. The context "philosophy of inquiry" Dewey (1938b) used is similar to engineering education programs' "problem solving skills". From Mina's observations through John Dewey's perspective, it can be concluded that in the context of problem solving, today's bloated education system does not promote nor produce problem solvers. In fact, due to the lack of flexibility and emphasis on "discovery aspects of education", development of problem solving skills may also be inhibited. The adverse effects of current education system can be observed in students' behaviour towards education which includes short retention spans and lack of determination in improving knowledge.

2.4 Cooperative Learning (CL) and Problem-Based Learning (PBL)

How do people learn? Based on rigorous research by Donovan, Bransford, and Pellegrino (1999), there are three vital discoveries on human's learning process:

i. Students have presumptions about the knowledge they are acquiring before coming to classroom. Many research experiments show the persistence of pre-existing understandings. Therefore, teaching has to integrate their pre-existing knowledge in order to be effective.

ii. When comparing novice and professional learning and transfer, research suggests that in order to develop competence, students must have deep understanding of the factual knowledge, understand the facts/ideas in the context of a conceptual framework, and organize knowledge in certain ways which can facilitate retrieval and application.

iii. Research on performance of experts and research on meta-cognition also suggests that learners can be taught to define their learning goals and monitor their learning progress.

How Do People Learn? Driscoll (2002) suggested that human learn using the following principles:

i. Learning occurs in a certain setting. Without an appropriate setting, learning success is improbable.

ii. Learning must be active. During education process, leaners must have a clear focus and an active mind. "Tell me I forget, show me, I remember, involve me, I understand". Learners have to make connections between the new knowledge and existing knowledge, and construct meaning from their own experiences.

iii. Learning involves socializing. Learners must collaborate with their peers and teachers in order to understand different viewpoints and complete learning tasks.

iv. Learning needs reflection. Learners benefit from the opportunity to express and evaluate themselves.

Based on the discoveries' of human learning process, and the principles of human learning as mentioned above, cooperative learning (Johnson, Johnson and Smith, 2006) and problem-based learning (Yadav et al., 2011) are two types of active learning (Felder and Brent, 2009) that can facilitate both, thus, enhancing the learning process.

2.4.1 Active Learning

Active learning is a teaching and learning technique that involves students in learning activities rather than passively listening to lectures. The activities include discussing, reading, higher-level thinking, reflecting, presenting, etc. Active learning has been shown to enhance learning; this is hardly surprising because learning is a naturally active process. Students from diverse learning styles can adapt to active learning because it gives the responsibility of organising what is to be learned in the hands of the learners (Felder and Brent, 2009). There are many subsets of active learning techniques. Cooperative learning and problem-based learning, in particular, are widely used in higher education (Felder and Brent, 2004a; Johnson, Johnson and Smith, 2006).

2.4.2 Cooperative Learning (CL)

The proper conceptual model of CL was introduced to engineering education in the early 80's (Smith, Johnson and Johnson, 1981). Since then, its use was refined and reported by many engineering educators (Smith, 1995; Felder, 1995; Prince, 2004; Smith, et.al., 2005). It is a learning technique that involves the interaction of students in a small groups so that they work together to maximize their own and each-others' learning (Smith, et.al., 2005; Smith, Johnson and Johnson, 1981). It is well recognized as a pedagogical practice that promotes learning, higher level of thinking skills, pro-social behaviour, and greater understanding of learners with diverse learning, social and adjustment needs (Cohen, 1994). It also induces generic skills, such as communication, interaction and interpersonal skills, teamwork and leadership skills, self confidence and self esteem. In fact, Johnson, Johnson and Smith (2006) suggested that there is no other pedagogical practice that simultaneously achieves such diverse outcomes.

In CL, students are expected to seek help from peers rather than from instructors. It does not replace the need for instructor but instead replaces individual lecture and drill. When used effectively, each group member will strive to help each other grasp the concept. The success of the team eventually relies on the ability to confirm the understanding of each group member (Slavin 1995). Social interaction among students can create collaboration, leading to a positive impact on learning (Jonassen, et al., 1995). Through collaboration, students discuss, defend, critique and reflect ideas or knowledge. According to Harasim (1989), through a discussion and interaction among peers, students will engage in constructing knowledge.

According to Slavin (1995), cooperative learning is supported by two major categories of theories: motivational theories and social cognitive theories. Motivational theories include expectancy-value theories, goal theories, and self-determination theories, proposed by Bandura’s (1993) self-efficacy theory, and Covington’s (1992) self-worth theory. Social cognitive theories proposed by Vygotsky’s (1978) zone of proximal development, Piaget’s (1964) theory of cognitive development, and Dewey’s (1963) theory of enquiries. It is also supported by team effectiveness by abiding to its principles (Smith and Imbrie, 2004).

2.4.2.1 Motivational Theories

Motivation plays very important roles in driving learning (Svinicki, 2005). It is the one of the main bases for engagement in learning (Urban and Schoenfelder, 2006). According to Pintrich and De Groot (1990), there are three major theories that described motivation: expectancy-value theories, goal theories, and self-determination theories. As mentioned by Eccles and Wigfield (2009), and reported by Matusovich, Streveler and Miller (2009), expectancy-value theories conceive that motivation to perform a learning task depends on two dimensions: “expectancy of success” in the given task, and the “value” attributed to effectively performing the task. Expectancy of success is related to three factors: (a) how a learner attributes her past success or failure; (b) how a learner perceives competence; and (c) how a learner maintains self-esteem. These factors are discussed in more details in attribution theory (Weiner, 2000), self-efficacy theory (Bandura, 1993) and self-worth theory (Covington, 1992). The “expectancy” dimension answer to the question of “Can I do this task?” The second category of expectancy, the value theories answers to the question of “Do I want to do the task?”. Wigfield, (1994) have identified four types of task values: extrinsic value, intrinsic value, utility value, and cost.

Weiner’s (2000) attribution theory assumes that motivation is affected by how people attribute their past success or failure. According to Bandura’s (1993) self-efficacy theory, if an individual regards capability as “acquired”, they will continue to strive towards personal development and stay committed with their aim. In contrast, when an individual views his/her capabilities as “inherent”, they tend to circumvent challenging tasks in the anxiety of recognizing personal disabilities in case of unsatisfactory performance. Similarly, Covington’s (1992) self-worth theory assumes that learners with low confidence often avoid working hard so that they can attribute failure to level of effort exerted to retain their sense of control and self-worth. Based on the motivational theories, Liao (2005) suggested that in order to enhance motivation, instruction needs to help learners perceive competence as acquired skills and to enhance their sense of control over learning tasks. Making the learners believe that excellence is achievable by efforts and that they can make a difference, is attainable by enabling students to make improvements on their past self-performance rather than being graded by the performance of others. In cooperative learning, this pedagogical practice is called “equal opportunities for success” (Liao, 2005).

Goal setting theory argues that human behaviors are controlled by goals and that the setting of personal goals are in turn influenced by factors such as group goals, role models, encouragement, and feedback (Locke and Latham, 1990). These factors are compatible with Slavin’s (1995) model of cooperative learning, and Smith and Imbrie's (2004) group performance classification of learning teams. For example, the goal setting theory argues that having team goals on top of personal goals brings about higher goal commitment to the personal goals than having personal goals alone. Correspondingly, the model of cooperative learning argues that the setting of team goals will trigger motivation to learn, motivation to encourage team members to learn, and motivation to help team members to learn. While some critics of cooperative learning (e.g., Kohn, 1991a, 1991b) argue that extrinsic motivation triggered by cooperative learning can negatively affect intrinsic motivation. Proponents of cooperative learning believe otherwise. In this regard, self-determination theories are in line with the perception of cooperative learning advocates. Deci et al. (1991) presents four forms of behaviors based on degree of motivation internalization. It argues that extrinsic motivation can facilitate intrinsic motivation and transfer a learner from the right (controlled and extrinsic) toward the left (self-determined and intrinsic).

2.4.2.2 Social Cognitive Theories

Cooperative learning is also reinforced by social cognitive theories proposed by Dewey (1964), Piaget (1964), Vygotsky (1978), and Bruner (1990). Vygotsky (1978) contended that socialization is the groundwork of cognition development, and that the process of cooperation with peers benefits learners cognitively because it allows learners to work close to one another's zone of proximal development. Piaget's theory of cognitive development (1964) provides rationale for cooperative learning in a similar way. For Piaget, individuals are responsive to cognitive growth only when they are in a condition where they can understand the concept. Working with peers allows individuals to help each other move to the next cognitive stage. In addition, Piaget's equilibration theory (1964) argues that cognitive developments consist of conflicts, which must be overcome through the process of equilibration, including assimilation and accommodation. Equilibration can be achieved by means of both individual and social activities. Dewey (1964) and Bruner (1990) viewed involvement in social environments and interpersonal communications is of importance to the cognitive development. Dewey (1964) concluded that learners have to obtain experience by being actively involved and cooperating with one another.

2.4.2.3 Team Effectiveness

When beginning to think about why cooperative learning and complex problem solving work well together, consider that individuals often get stuck in problem solving, but teams of students tend to keep going and other team members learn more because they have to teach others. A team is a vast set of versatile individuals who cooperate with one another in order to achieve a common goal. Smith (2007) states that teams are social entities. Guzzo and Dickson (1996) states teams as a group "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 (1993) define teams in terms of their characteristics by claiming that a group is a team if the characteristics of job design, interdependence, composition, context, and potency are demonstrated. Locke and Latham (1990) proposed their goal-setting and task performance theory in the field of industrial-organizational psychology which speaks to the necessity of teams setting goals, both conscious and unconscious, in order to perform effectively. Scholtes (1998) listed new competency of leaders, where team working is one of the most important attributes of an effective leader.

Johnson, Johnson, and Smith (2006) listed five elements important for successful teams:

i. "Positive interdependence between team members to accomplish a task;
ii. Individual accountability in completing their share of the work and mastering all material
iii. Face-to face interaction in at least part of the task;
iv. Appropriate use of interpersonal skills, like communication, leadership and conflict management; and

v. Regular self-assessment of group functioning to identify any improvements that needs to be made and maintain those that functions well".

In terms of team effectiveness, Smith and Imbrie (2007) classified teams into four levels;

i. Pseudo group – members are competing with each other in performing a task.
ii. Traditional group – members working with each other with minimum helping and sharing.
iii. Cooperative learning group – members dependent on each other, and believe that their success depends on the effort of all team members.
iv. High-performance cooperative group – team encounters all criteria of cooperative learning group and surpasses all reasonable expectation such as members' mutual concern for each other's personnel growth.

Meanwhile, Imbrie, Maller, and Immekus (2005) classified the effective teams as potency, interdependency and goal setting. Teams with shared belief that they can be effective are categorized as "potency". Teams that cooperate among each other to accomplish a task are considered as "interdependency". Teams that established goals to accomplish a given task are categorized as "goal setting".

2.4.3 Problem-based Learning (PBL)

They are many instructional approaches that situated learning such as inquiry-based learning, case-based learning, project-based learning, discovery learning, and PBL (Prince and Felder, 2007). These approaches, in the tradition of Dewey (1938a), argue the importance of practical experience in learning. Students are responsible for their own learning. They learn among themselves by solving ill-structured problems, and reflecting on their experiences (Barrows and Tamblyn, 1980).

In PBL, a realistic problem is the starting point of learning, which engaged the learner to find a solution (Barrows, 1996). Students collaborate in small teams to identify, find and construct knowledge on new concepts that they need to learn in order to solve the problem. PBL is not only about giving and solving problems, but it is also “about creating opportunities for students to construct knowledge through effective interactions and collaborative inquiry” (Savery, 2006). As such, it is not surprising that PBL is ranked on the highest end of student-centred techniques (Duderstadt, 2008). It is characterised by the following features (Barrows and Tamblyn, 1980b; Tan, 2003; Hmelo-Silver, 2004):

i. A realistic problem, which captures the students' interest, is the starting point of learning
ii. The problem challenges students' existing knowledge, attitudes and competencies, leading them to identify new knowledge (or learning issues) needed, and shortcomings that have to be corrected.
iii. The responsibility and direction of learning is assumed by the students; faculty members are only there to facilitate students' thinking, learning and group functioning to help them resolve the problem.
iv. Information mining from various sources, and utilization of evaluation to analyse what is really useful.
v. The process of identifying learning issues and problem-solving is as important as acquiring new knowledge to arrive at the solution.
vi. Students learn collaboratively, where they need to interact and communicate to share knowledge, discuss their understanding and debate conflicting opinions.
vii. Synthesis of various knowledge and information to arrive at the solution.
viii. Reflection of the students' learning experience.

The goal of PBL is to develop students to be self-learners. To help them know how to identify gaps in their own knowledge, how to find the information they need, how to develop their own knowledge base, and learn how to access their own progress and development. According to Barrows and Kelson (1995), which is supported by extensive research by Hmelo-Silver (2004), PBL is designed to help students:

i. “Construct an extensive and flexible knowledge base;
ii. Develop effective problem-solving skills;
iii. Develop self-directed, lifelong learning skills;
iv. Become effective team players;
v. Become intrinsically motivated to learn; and
vi. Identify deficiencies that they need to improve on through reflecting the learning process”.

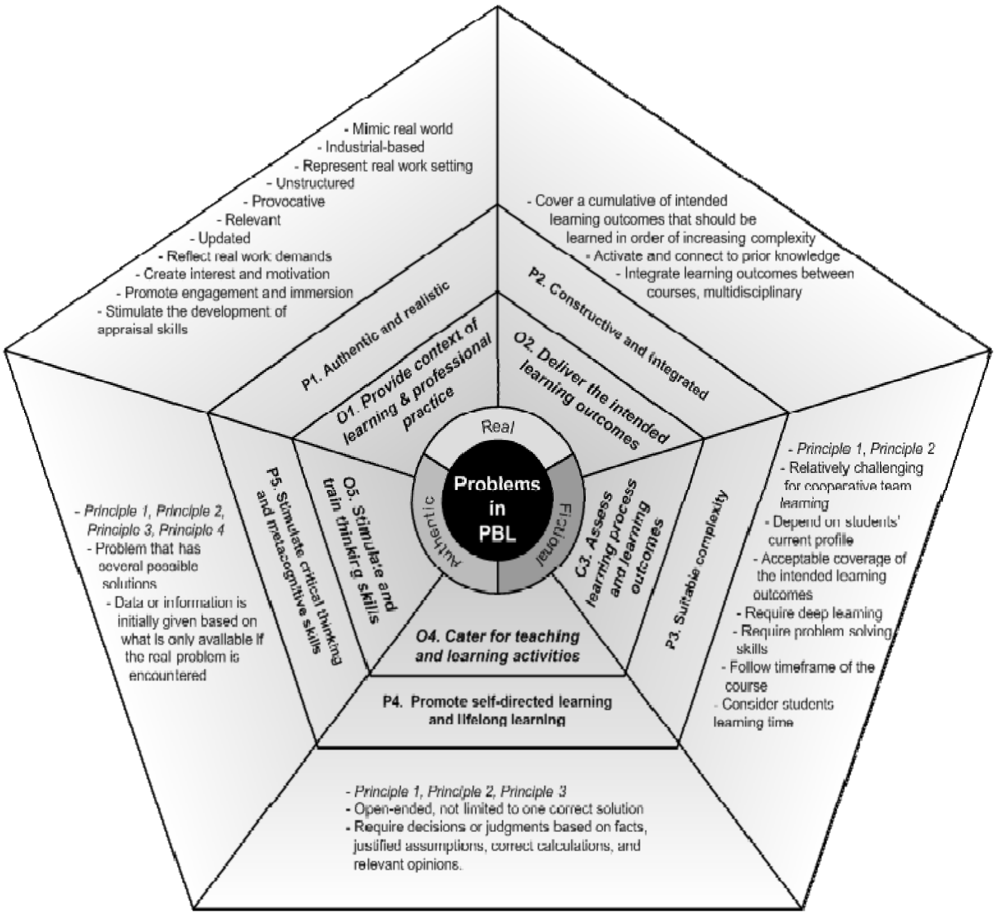
There are at least two key issues of learning through problem solving in PBL approach. First, the approach emphasizes for the learners to work together, actively constituting knowledge in teams. And secondly, both the students and the lecturers' roles are changed. Lecturers no longer pose as the main repository of knowledge, but the lecturers now facilitates the cooperative learning, guiding the students by providing them with open-ended questioning. This enables the students to think visibly and be involved in the group process. The self-directed learning in PBL is a distinguishing feature unique to it. The learning process of the students becomes their own responsibility, which requires them to be reflective and think critically about the knowledge being learned (Scardamalia and Bereiter 2006). Students are required to use their knowledge and to be self-directed learners. Thus, the students' beliefs and expectations are important aspects that have substantial impact on solving problems.

PBL is the practical embodiment of over 50 years of research in the cognitive science, which has taught students how to learn. In this day of extremely rapid increase of our sciences and technologies knowledge base, it is considered as the best educational strategy to produce engineers who are capable of keeping current once they are practice (Duderstadt, 2008). To achieve the most efficient, long lasting learning, there are known principles that can be built into any educational method.

The origin of PBL was in North America in the 1960s where it started with medical practice. Today, it is increasingly used in many curriculum areas including engineering. Some universities even shifted their whole curriculum to PBL, and various medical schools rely on it instead of traditional curriculum. In the PBL curriculum, “the problems are the curriculum” (Biggs, 1999). PBL focuses on real-world problems rather than theoretical case studies which have neat, convergent solutions. Only through the struggle with actual problems will students "acquire knowledge, content-related skills, self-management skills, attitudes, know-how: in a word, professional wisdom" (Biggs, 1999). Students who practice PBL will obtain what they need to know in order to perform and behave as a practicing professional.

An important part of PBL is that the problem comes first. In other words, the content is given in the context of real-world problems (Bound, 1985; Bound and Feletti, 1991; Woods, 2000). PBL contrasts with the traditional teaching at which a lecture format precedes 'end-of-the-chapter' problems. Through PBL, students will have to determine in teams what they are aware of, what knowledge they are deprived of and they also must learn to solve the problem. These are the steps to understanding the case and what must be done next. The nature of the case hinders the possibility of simple answers. Students will have to look beyond their textbooks in pursue of knowledge to solve the problems. The role of the instructor is merely to guide and facilitate the students' thinking and learning processes, keeping the answers sealed.

There are a number of criteria that characterize effective PBL problems (Dolmans et al., 1997; Duch, 2001; Wee, Kek and Sim, 2001; Tan, 2003; and Weiss, 2003). The criteria is summarized into five interrelated principles, aligned to the objectives of using problems in PBL, as shown in Figure 2.4.



(O – objectives, P – principles)

Figure 2.4: Principles of effective PBL problems (Jamaluddin, et al., 2010)

2.4.3.1 PBL Models

As a philosophy that needs to be adapted according to certain atmosphere and conditions of institutions and nature of the field which it is applied, PBL has many different model implementations worldwide. Consequently, a “one-size-fits-all” approach which can simply be implemented in each institution is almost impossible to consider. (Tan, 2003). Table 2.6 shows a summary of the some of the different PBL models used in different institutions (Graaff and Kolmos, 2003; O’Grady, Hong and Ng, 2004, Helmi, et al. 2009).

Table 2.6: Different PBL models

	Medical School Model (M-PBL)	**One-day One-problem Model (RP-PBL)**	**Problem-oriented Project Based Learning (PoPBL)**
Example institution used	McMaster University, Canada	Republic Polytechnic, Singapore	Aalborg University, Denmark
No. of students per group	8 - 10	5	2 – 7
Lectures - problem work	Few lectures	No lectures	½ lectures ½ project
Length of problem work	One week	One day	One semester
Pre-structure of problem	Medium	High	Low
'Teacher' direction	Low	High	Low to medium
Outcomes	Learning	Presentation + learning	Report, product, presentation + learning
Assessment	Individual Block+progress	Individual Daily+ 'understand'	Individual S-course+project

There are, however, essential features of PBL as listed above. The PBL approach sought to embed small groups of students in the role of a professional and present them with a messy, unstructured, real-world problem, based within the context of the profession, to solve. This is, in fact, the major driving force for learning. The problem should be well crafted to engage and immerse students in learning new issues, as well as challenge existing knowledge, skills and attitude. Students are then guided by cognitive coaches through the problem solving process and develop high levels of generic skills and attributes, along with the content specific knowledge and skills they require. PBL practitioners often claim that their learners are more motivated and independent in their learning (Woods et.al., 1997; 2000; Mohd-Yusof and Helmi, 2008; Yadav, et.al 2011). The PBL pedagogy sought to make students' thinking visible – it is no longer about making content visible as in the traditional mode (Tan, 2003).

Figure 2.5 shows PBL process implemented in Universiti Teknologi Malaysia (UTM), Malaysia. The whole process can be divided into 3 main phases.

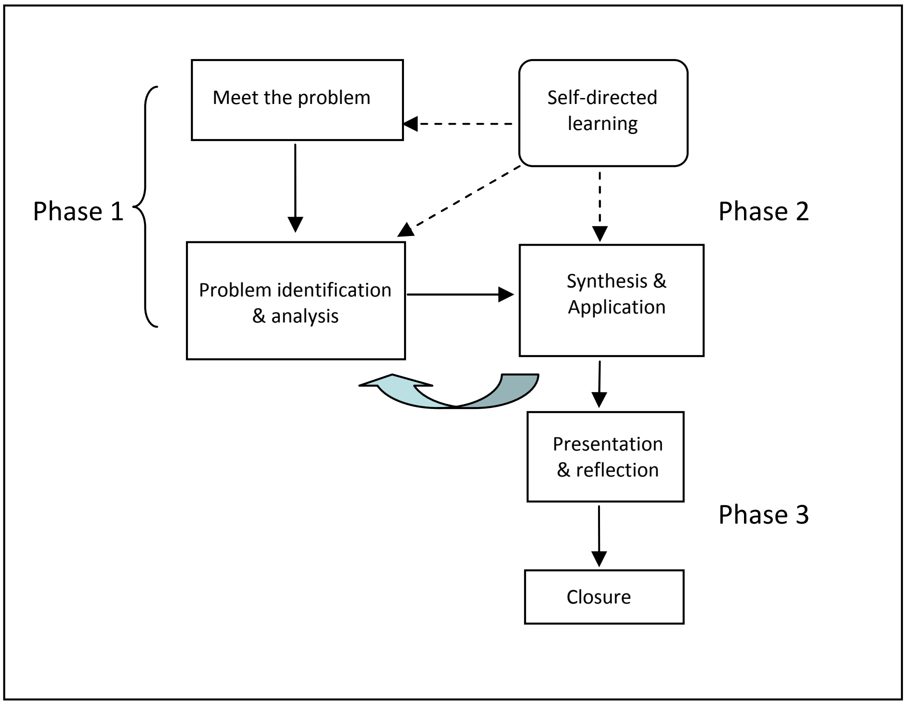


Figure 2.5: The complete UTM-PBL cycle (Mohd-Yusof and Helmi, 2008)

Phase 1

Phase 1 is necessary to prevent students from jumping to conclusions and try to rush to solve the problem without first understanding it. It consists of the following steps:

- Meet the problem - Problem scenarios are given a day or two before class time. The students read the problem scenario, reflect and articulate probable issues individually. They are encouraged to do background reading on the possible learning issues before coming to class. Students are asked to restate the problem in their groups to enable them to get the same mental picture of the problem and eliminate sweeping assumptions or biases.

- Problem identification and analysis - The teams reach a consensus on the problem statement. They analyse the problem through guided brainstorming to generate ideas. 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 that must be tackled through self-directed learning. Facilitators probe and guide the students so that they are on the right track in understanding the problem, as well as the learning issues identified. Self-directed learning may also be monitored by the facilitator during a class session.

Phase 2

Once the problem has been identified and analysed, self-directed learning will take place among team members. Nevertheless, students may need to return to Phase 1 once they have more information and knowledge. In Phase 2, the students undergo the following steps:

- **Self-directed learning, peer teaching and reporting -** Facilitators may give references or activities to provide scaffolding for students to learn new concepts. Students report their discovery from research and self-directed learning to their own teams. Part of this step may be performed in the classroom in the presence of facilitators. To facilitate this phase and ensure that students are able to learn the concepts correctly, each member in a team prepare peer teaching notes for his/her team mates and submit a copy to the facilitator. Team-based peer teaching can then be held during class time while being monitored by the facilitator. For difficult and/or critical concepts, an overall class peer teaching can be held, where one or two teams can be selected to present and conduct discussions.
- **Synthesis and application -** Information is shared and critically reviewed so that the relevant ones can be synthesized and applied to solve the problem. Facilitators at this stage 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.

Phase 3

Upon solving the problem, the students enter the third phase, where they go through the following stages:

- **Solution presentation and reflection -** The solution to the problem is presented in the form of a report and an oral presentation to the class, 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. This stage may be completed in a one-hour class period. Each student is required to submit a learning and reflection journal at the end of a case study. There is also an overall discussion on material and skills learned from the case study.

While applying PBL to engineering students who are alien to the problem solving and self-learning environment, students are likely to feel uneasy. The facilitator plays a major role at these times. They need to convince the students they are researchers searching for knowledge and problem solutions. Students will often anticipate their facilitators to tell them each and every thing that needs to be done. The normal attitude of most engineering students or rather, the attitude of mere students wants to know what must be done to obtain a grade. Some students may even find changing to PBL format and leaving behind the old lecture hall scary and simply horrifying. Supporting and motivating students can enlighten the student at dire times. An important motivational issue is in terms of commitments and responsibilities. These elements can be observed in each individual as the work together and help out one another.

2.4.5 Integrating Cooperative Learning (CL) into Problem-Based Learning (PBL)

PBL, which has constructivist underpinnings, is a philosophy that needs to be adapted to the specific condition and environment of the institution and the nature of the field in which it is applied. This can be seen in the different models of PBL implementation throughout the world as mentioned previously. It is an inductive learning approach that embeds small groups of students in the role of a professional and presents them with a messy, unstructured, realistic (if not real) problem, to solve. The problem should be well crafted to engage and immerse students in learning new issues, as well as challenge existing knowledge, skills and attitude. Students are guided by cognitive coaches through the PBL cycle to learn and solve the problem. PBL is "not only about infusing problems into the class, but also about creating opportunities for students to construct knowledge through effective interactions and collaborative inquiry." (Tan, 2003)

Supporting and monitoring students' learning in small groups by a floating facilitator can be challenging in a typical class while implementing PBL. It is typical for students to resist working in groups, be it in laboratories or class projects, because of negative prior experiences (Felder and Brent, 2007). Therefore, the support needed does not only involve cognitive coaching at different PBL phases, guidance and monitoring to develop team working skills in students is also essential. In a proper Cooperative Learning (CL) environment, part of the monitoring, support and feedback can be attained from peers, especially team members, instead of solely relying on the facilitator. In fact, support can be further enhanced by developing the whole class into a learning community. To achieve this, Duch, Groh, and Allen (2001) suggested CL aspects to be integrated with PBL, thus becoming Cooperative Problem Based Learning (CPBL). This is in-line with the recommendation from Prince (2004) that the two methods be combined to take advantage of the natural synergy between them. The CPBL framework and the form of incorporation between CL and PBL are presented in Chapter 4.

2.5 Conclusion

This chapter has described thoroughly the literature reviews on future engineers and engineering educations, problem solving skills in engineering, methodologies of active learning techniques particularly CL and PBL to better educate future engineers. It ends up by highlighting the integration of CL with PBL, thus enhancing team-based problem solving skills. Understanding the attributes and needs of future engineers are important in order for engineering institutions to design the desired engineering curriculum. Engineering is all about problem solving. CL and PBL are promising teaching and learning methodologies of enhancing the skills. However, to successfully educate the desired future engineers, with the challenging of the future engineering world is a challenge. So, it is important to address how to successfully educate future engineers to become better problem solvers, particularly the workplace problem. In order to educate future engineers to become better problem solvers, these literature reviews was summarized in the theoretical framework as shown in Chapter 1. It highlighted the success factors for enhancing problem solving skills. The following chapter will discusses in detail how research on the enhancement of problem solving skills among engineering students is conducted. The result of the study is used as a proposed model in the enhancement of the skills.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter elaborates the topics related to the methodology adopted in this research. Mainly the discussion is divided into two areas: quantitative and qualitative methodologies. The choice of research design is initially discussed, which is then followed by research framework and subject of the study. In the quantitative methodology, instruments' development and selection are explained, including their respected technical characteristics. This is then followed by the discussion on qualitative methodology, and its respected technical characteristic. The data collection and data analysis will then be explained before the chapter is concluded.

3.2 Research Design

Initially a preliminary survey was carried out and research instruments were selected and formulated based on the objective and research questions described in Chapter 1. This was carefully done so that finally, promising practices to enhance engineering students' problem solving skills is proposed. The course chosen for this particular study is the Process Control and Dynamics that is taught by an experienced CPBL practitioner.

Both quantitative and qualitative data were collected and analyzed to evaluate and formulate process of enhancing problem solving skills among students throughout the semester. The distinction between qualitative and quantitative in social science research is essentially the distinction between numerical and non-numerical data (Babbie, 2010). In this research, qualitative analysis serves as a complement to the quantitative results. It allows the researcher to fully explore the multiple variables and detail practices that facilitate the development of students' problem solving skills (Merriam, 2009; Yin, 2009). The naturalist context of qualitative analysis allows the researcher to investigate the variables in a holistic, in-depth manner, while preserving them without the risk of controlling or losing the very factors that contribute to the development of students' problem solving skills (Yin, 2009). The insight gained from this exploration is used to generate hypotheses that guided the research (Merriam, 2009). Miles and Huberman (1999) suggest linking qualitative data when: (a) the research is both confirmatory and exploratory in nature; (b) when quantitative data can facilitate the qualitative aspect in the study; and (c) to corroborate data by way of triangulation. This study meets all three conditions.

3.3 Operational Framework

Referring to Figure 3.1, this research is divided into three phases. Phase I is pilot study, course and class familiarizations, and selection and development of quantitative research instruments. Phase II is data collection, followed by phase III which is data analysis and models' development. Meta-analysis is done via extensive literature reviews throughout phase I. Through meta-analysis, several related instruments were selected and developed. Using the selected and developed instruments, pre-test and post-test are done as a pilot study for instruments' reliabilities and validities. At the same time, class observations for primary investigation and familiarization are done for qualitative analysis. Class observation and meta-analysis are used to formulate research variables.

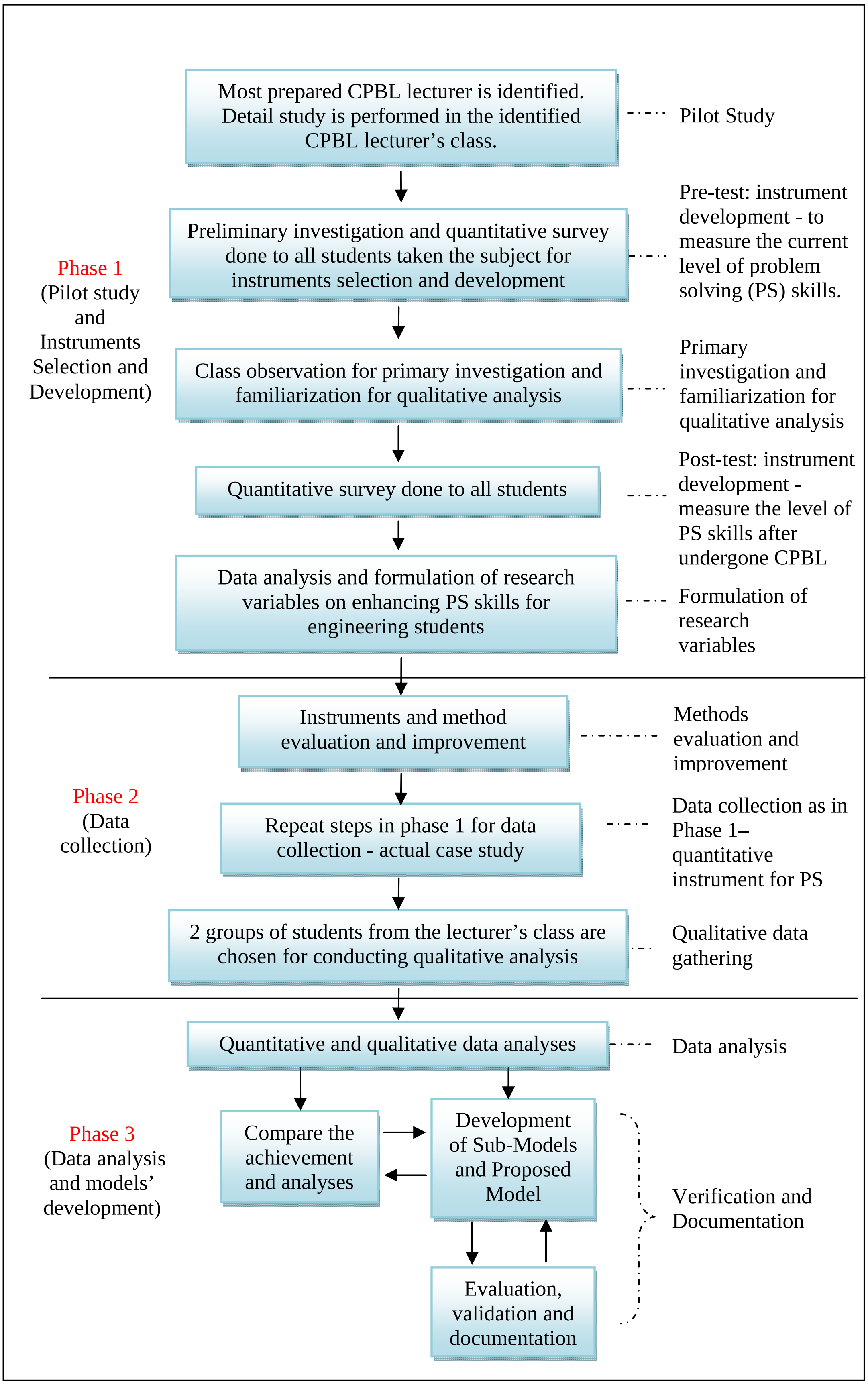


Figure 3.1: Operational framework

Research instruments selection and development are finalized in Phase II. This is done mostly through meta-analysis, class observations, getting feedback from experts' opinions, and interviews. These evaluated and validated instruments were used for quantitative data collections. Data for qualitative study are gathered throughout phase II. This phase took duration of a year. Phase III is data analysis, synthesis and models development. Based on the analysis, results of the study are identified and proposed. This is then followed by development of several sub-models of promising practices. These promising practices are verified in this phase, and a model for enhancing problem solving skills among engineering students is proposed. Documentation is done throughout this phase.

3.4 Subject of the Study

The implementation of CPBL in a third year chemical engineering undergraduate course in Universiti Teknologi Malaysia (UTM) is studied to analyze the enhancement of problem solving skills among students. This Process Control and Dynamic course in chemical engineering department typically has 30 to 60 students in a class. At the time of this study, the department offered three sections for the course. CPBL had been implemented in the course since 2003. There are 4 problems given throughout the semester, with different scenarios and content outcomes (see Appendix B). The first problem was the shortest and the simplest, while the second and third problems were challenging, both in terms of technical content and the required thinking skills. The last problem was a real industrial problem that required students to act as consultants to design control systems. A detailed description on the problem designed is discussed in Chapter 4.

3.5 Quantitative Analysis

Quantitative analysis is done to find answer to the first research question, which is to what extent the CPBL approach enhanced problem solving skills among engineering students. In the study the researcher critically analyze the influence of CPBL towards students' knowledge, confidence and cognitive process. With regards to this, the study analyzed the students' problem solving process, self-directed learning, and reflection. It also study the influence of CPBL towards team-working, and students' motivation and learning strategies as suggested by many literatures, such as from Barrows and Kelson, (1995) and Hmelo-Sliver (2004). These factors are very much interrelated to one another towards becoming an effective problem solver, thus, becomes the sub-questions for the first research question. The related sub-questions are as follows:

i. Do students become better problem-solvers in terms of its processes?
ii. Do students improve their ability to reflect the process they went through in solving problems?
iii. Do students become better self-directed learners by engaging in solving problems?
iv. Do students improve their learning motivation and their employment of learning strategies through CPBL that will enhance their problem solving skills?
v. Do students improve their team working skills by solving problems cooperatively in CPBL which lead to enhancement of their team-based problem solving skills?
vi. Do students become better problem solvers in terms of acquiring their problem solving assets through CPBL?

These questions are quantitatively answered using several instruments. The first instrument is the designed Engineering Problem Solving Instrument (EPSI). Other instruments are Motivation and Learning Strategies Questionnaire (MSLQ), and Team Working Effectiveness Score (TWES). Since the EPSI is a designed instrument, it will be thoroughly discuss in the following section. It is then followed by the discussion about MSLQ and the TWES.

3.5.1 Design of Engineering Problem Solving Instrument (EPSI)

Designed based on engineering problem solving concepts derived from the literature, the Engineering Problem Solving Instrument (EPSI) is developed to measure improvements in problem solving elements as perceived by engineering students upon going through CPBL in a course. The instrument is designed to gauge the enhancement of problem solving skills as defined by Jonnesen (2000; 2006), Woods (1994; 2000; 2004) and Mayer and Wittrock (2006). Unlike past assessments, such as those developed by Ruskins (1967), Woods (1994), and Carter, Heywood and Kelly (1986), this assessment is developed not as a mean 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 3.1 shows a summary of the literature related to the engineering problem solving skills which was discussed in chapter 2. From the literature shown in Table 3.1, 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 3.2.

In defining the constructs of the instrument, 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. Figure 3.2 illustrates the engineering problem solving process, which is slightly modified from Phillips, 2008. Table 3.3 summaries the difference between Phillip's (2008) and the modified version of engineering problem solving process.

Table 3.1: Summary of the essentials related to engineering problem solving (Helmi, et al., 2011).

Literature Review	Concept	Category
Jonassen, Strobel and Lee (2006) Mayer and Wittocks (2006) Strobel and Barneveld (2009)	• Ill-structured versus well-structured • Ill-define versus well-define and routine-non-routine • Emphasize important of different support structure for different problem topology	**Problem topology**
Woods (1996) Ruskins (1967) Carter, Heywood and Kelly(1986)	• Devised questions 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 problem solving skills**
Fuller and Kardos (1980) Woods (1994;1996)	• 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 et. al.(1956) Biggs and Tang (2010) Piaget (1954) Chi, Feltovich and Glaser (1981)	• 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 (1945) Wales and Stager (1990) Eck and Wilhelm (1979) Woods (1996) Phillips (2008)	• 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 Wittrock (2006) Adams (2008)	• Knowledge and cognitive processes • Belief-motivation-expectation in between	**Problem solving assets**
O'Donnell, Reeve and Smith (2009) Savery (2006), Savery and Duffy (1995) Hmelo-Silver (2004) and Barrows (1996) Woods (1994;1996; 2000) Johnson, Johnson and Smith (2006)	• CL - Social constructivism • PBL – Constructivist • PBL – Medical • PBL – Engineering • CL principles	**CL and PBL**

Table 3.2: Summary of the Essentials Related to the Development of EPSI (Helmi, et al., 2011).

Category	Concepts Related to CPBL	Literature Review
Engineering Problem Solving Skills		
Topology	All problems posed are ill-structured, open-ended	Jonassen, Strobel and Lee (2006)
Design of instrument to gauge students' problem solving enhancement	Self-evaluation on students' problem solving skills enhancement upon attending CPBL	Mayer and Whittocks (2006)
Heuristics	Applying MPS concept, but in a course instead of institutionalized 4 stages = 4 problems	Woods (1996)
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 (2010), Piaget(1954), Chi, Feltovich and Glaser (1981)
Engineering Problem Solving Elements	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 process: Problem identification Problem analysis and synthesis Solution generation Important elements of CPBL cycle: Reflection Self-directed learning	Phillips (2008) Mohd-Yusof and Helmi (2008)
Engineering Problem Solving Assets	The detail elements in each constructs are designed based on knowledge, confidence and process	Adams (2008)
CPBL	The instruments is designed for CPBL – a hybrid of CL and PBL • CL - Social constructivism • PBL – Constructivist • PBL – Engineering • CL principles	O'Donnell, Reeve, Smith (2009) Savery and Duffy (1995) Woods (2000) Johnson, Johnson, Smith (2006)

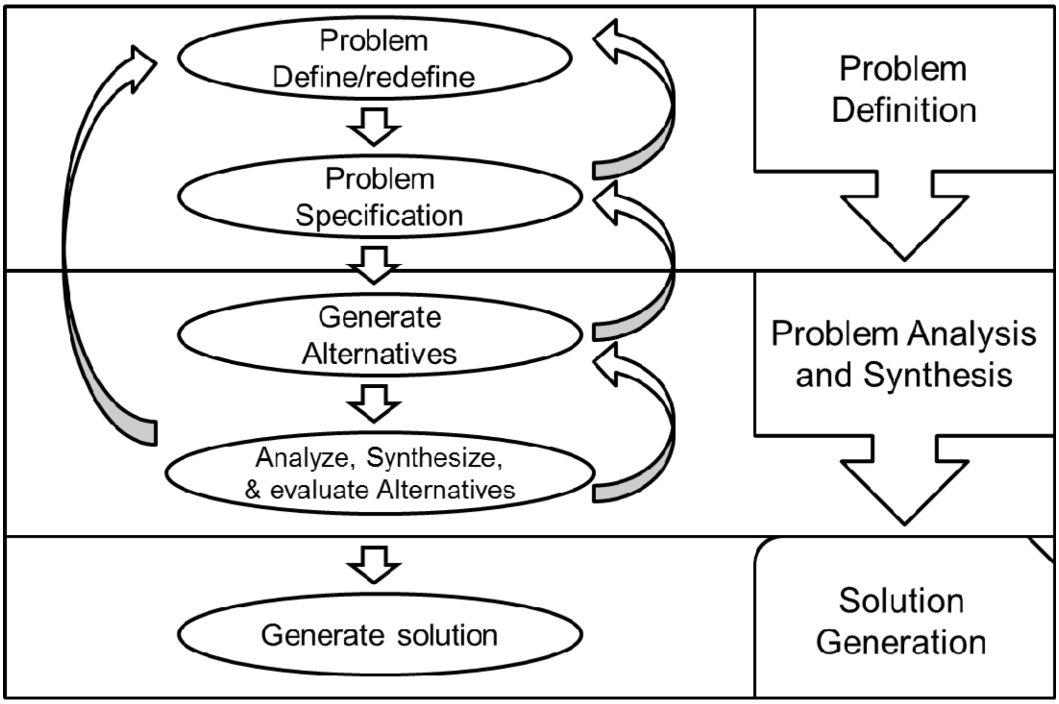


Figure 3.2: Engineering problem solving process (modified from Phillips, 2008)

Table 3.3: Differences between Philips' and the modified version of engineering problem solving process

Modified		**Philips'**		**Reasons**
Problem definition	Problem define/ redefine	Definition	Define the problem	(same)
	Problem Specification		Review problem constraints/ criteria	To include other factors such as the knowledge gap and learning issues.
Problem Analysis and Synthesis	Generate Alternatives	Strategies	Generate alternative	Rename "strategies"
	Analysis, Synthesis and evaluate alternatives		Test/evaluate alternative	To include analysis and synthesis. Changes in the iteration process.
Solution Generation	Generate Solution	Solution	Select final solution	(same)

Referring to Figure 3.2 and Table 3.3, the differences between Philips' and the modified version are: (1) in Philips', the "problem specification" in foundational phase of "problem definition" is called "review problem constraints/criteria". The researcher believed that the process require more than just reviewing problem constraint/criteria. For example, what are the knowledge gap and the learning issues? (2) In Philips', the foundational phase of "problem analysis and synthesis" are named "strategies". The researcher made the changes because of the believed that "strategies" applied to all foundational phases, which include problem definition and solution generation. (3) In Philips', the "strategies" phase are divided into two, which are "generate alternative solution" and "evaluate alternative solutions". The iteration processes of the "strategies" phase is from "generate alternative solution" to "define problem" and to "review problem constraints"; and also from "evaluation alternative solution to "review problem" and "generate alternative solution". In the modified version, the iterations at the "problem analysis and synthesis" phase are from "analysis, synthesis and evaluate alternatives" to "generate alternative" and to "problem redefine"; and also from "generate alternatives" to "problem specification". For the researcher, these modified iterations are more reasonable and practical. This modified Phillip's model is used in this research since it is simple, concise and more practical to be incorporated with CPBL approach.

Reflection and self-directed learning are another two very important components of CPBL, which are elements that directly enhanced problem solving skills among students that undergo CPBL courses (Mohd-Yusof and Helmi, 2009). Considering the entire problem solving elements, this EPSI instrument is designed based on five constructs:

i. problem identification,
ii. problem analysis and synthesis,
iii. solution generation,
iv. self-directed learning, and
v. reflection.

Each construct of the instrument was further divided into three problem solving assets: knowledge, confidence, and cognitive process. In here, the component of expectation/belief/motivation from Adams (2008) are rename as "confidence", which the researcher believed is more complete and rich in its meaning, as compare to the one proposed by Adams (2008). 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 (Adams, 2008).

Confidence is a degree of belief/motivation/expectation 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 (Adams, 2008). 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 (Jonassen, 2000). 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) cycle. Although PBL has constructivist underpinnings, incorporating CL into PBL to become CPBL includes social interdependency and social constructionist principles into the model (Savery, 2006; O'Donnell, Reeve and Smith, 2009). Nevertheless, the constructivist elements are still predominant because the model emphasizes learning starting with individual construction before the participation of students working together in their team as well as in the learning community of all their classmates developed based on CL principles (Johnson, Johnson and Smith, 2006). The following paragraphs discuss briefly this CPBL model with respect to the five constructs:

i. **Problem identification**. Students individually understand and restate the problem, before going to their teams to discuss 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.

ii. **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.

iii. **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.

iv. **Reflection**: Each student is required to submit a learning and reflection journal. The engineering problem solving diagram as shown in Figure 3.2 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 (Phillips, 2008). From this, new ideas might emerge. This is where critical thinking enhanced in the problem solving activities (Hmelo-Silver, 2004). 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.

v. **Self-directed learning**: Students will be conscious throughout the process of learning and solving the 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 so that they can easily discuss with their team mates and classmates, whether in the form of face-to-face interaction, or virtually. 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 3.4, under the category of problem solving skills. The instrument follows the structure of Woods' (1996) My Role Is Questionnaire (MRIQ) to provide a contrast as well as continuity between deep and surface learning approaches (See Appendix C). The surface and deep options are in line with Piaget's (1954) assimilation-accommodation and Chi's (1981) 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 3.4. Option 1 is for considering surface thinking while Option 2 is for deep thinking. Table 3.4 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 (see Appendix D). Instructions given on the front page of the form, shown in Appendix E, 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 3.4: Problem identification constructs development (Helmi et al., 2009)

	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.

3.5.1.1 Technical Characteristics

This developed EPSI were given to all students in the three Process Control and Dynamic sections in the Chemical Engineering Department, as a pilot study to investigate the reliability of the instrument. Based on the result, 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 .75, .81, .81, .73 and .79, respectively. As for the problem solving assets, the reliability scores are .82, .84 and .88 for knowledge, confidence and cognitive process. The overall Cronbach's alpha score for the EPSI instrument is .95. See Appendix F for the reliability analysis result. For validation, the instrument had been validated by experts in problem solving and cooperative problem-based learning. See Appendix G for the instrument's experts' validations.

3.5.2 Motivated Strategy for Learning Questionnaire (MSLQ)

The MSLQ (Pintrich, et al., 1990; 1993) is an instrument designed to measure students' learning motivation and their employment of learning strategies for a university course. The MSLQ is anchored in a general cognitive view of motivation and learning strategies, with the student characterized as an active processor of information whose beliefs and cognitions provide valuable insight to instructional input (Pintrich, et al.,1993a). The theoretical framework that underlines the MSLQ is an adaptation of a general expectancy-value model of motivation (Pintrich and De Groot, 1990). MSLQ contains two main sections: a motivation section and a learning strategies section. The structure of the MSLQ used in this research is shown in Table 3.5.

Table 3.5: Selected MSLQ

Section	Component	Scale
Motivation	Value	1. Intrinsic Goal Orientation 2. Extrinsic Goal Orientation 3. Task Value
	Expectancy	4. Control of Learning Beliefs
Learning Strategies	Cognitive/Meta-cognitive Strategies	5. Organization 6. Critical Thinking
	Resource Management Strategies	7. Effort Regulation 8. Help Seeking

3.5.2.1 Motivation

For this research, the motivation section is divided into two components: value and expectancy. Value component measures students' goal orientations and value beliefs for a course. It contains three scales: intrinsic goal orientation, extrinsic goal orientation, and task value scales. Intrinsic goal orientation refers to the degree to which students perceive a learning task in the course as an end to itself rather than as a means to an end. In other words, the students participate in a learning task to challenge themselves, to satisfy their curiosity, or to master the task. On the other hand, extrinsic goal orientation refers to the degree to which the students perceive a learning task as a means to an end. The students' participation in the task is motivated by external factors such as competition, grades, rewards, or performance. Task value concerns the degree to which the students perceive the course material in terms of interest, significance, and usefulness. Higher task value leads to higher degree of participation in learning. Expectancy component measures students' expectancy for success in a course. Control of learning beliefs concerns the degree to which the students believe that their efforts to study will bring about positive results.

3.5.2.2 Learning Strategies

The learning strategies section is divided into two components: (1) Cognitive and Meta-cognitive Strategies, and (2) Resource Management Strategies. Each component is further divided into various scales. In this study only four relevant scales are considered. Cognitive and meta-cognitive strategies component measures students' use of cognitive and meta-cognitive strategies with organization and critical thinking scales. Organization refers to making connections between substances to be learned by selecting main ideas, outlining, making diagrams, or making tables. Critical thinking involves making evaluations and applying prior knowledge to new contexts for problem solving.

Resource management strategies component measures students' use of resource management strategies. In this study only effort regulation and help seeking scales are considered. Effort regulation measures students' ability to commit to their learning goals by regulating their effort and attention when they face distractions, difficulties, or boring tasks. Help seeking measures students' ability to manage the supports of others by identifying someone that is able to provide assistance and then actively seek for help. These four scales consist of 19 items. See Appendix H for the form and the selected MSLQ questions used this research.

3.5.2.3 Technical Characteristics

Internal consistencies are estimated with Cronbach alpha for each scale (Pintrich, et al., 1993b). Table 3.6 presents the reliability level for respected MSLQ scale.

Table 3.6: Reliability level for respected MSLQ scale

Scales	Cronbach Alpha
Intrinsic goal orientation	.74
Extrinsic goal orientation	.62
Task value	.90
Control of learning beliefs	.68
Organization	.64
Critical thinking	.80
Effort regulation	.69
Help seeking	.52

The Cronbach alphas of the motivation scales ranged from .62 to .90; those for the learning strategies scales ranged from .52 to .80. All scales are associated with adequate alpha reliability levels for the purpose of the study. The overall Cronbach alpha value is 0.97.

3.5.3 Team Working Effectiveness Score (TWES)

For this research the theoretical construct for effective teams are in terms of interdependency, potency and goal setting. Teams that demonstrate “interdependency” have cooperation among team members to accomplish a task (Guzzo and Dickson, 1996). “Potency” is the shared belief by a team that they can be effective (Guzzo, et al., 1993). “Goal setting” is the ability of a team to set goals and sub-goals to accomplish a task (Locke and Latham, 1990). This framework is used in this research to assess team effectiveness. These characteristics distinguish “teams” from the broader term “groups.” By working cooperatively using teaming theory as a guide for skill development, students can be motivated toward the goal of performance on problem-solving tasks (Smith and Imbrie, 2004). See Appendix I for the TWES form used in this research.

3.5.3.1 Technical Characteristic

Evidence regarding the scale's psychometric properties was examined. Specifically, scores based on freshmen student data (N = 1,060) indicated that subscale internal consistency reliability for interdependency, goal setting, potency, and learning (Cronbach's coefficient alpha) estimates were .96, .92, .96, and .94, respectively, and for the total scale was .98. Results of a confirmatory factor analysis indicated that a one factor model fit the data, $\chi 2$ (254) = 316.15, p = .005, $\chi 2/df$ = 1.24, *RMSEA* = .02, *CFI* = 1.00, *GFI* = 1.00. This confirmed that items can be summed to create a composite score, thus operationalizing a definition of effective teaming that was based on a measure with construct validity evidence (Imbrie, Maller and Immekus, 2005)

3.6 Qualitative Analysis

In this research, qualitative analysis serves as a complement to the quantitative results. It is used to gain the understanding on how problem solving skills enhanced through CPBL among engineering students. The epistemology of the research is based upon interpretivist perspective (Chism and Douglas, 2008). The research strategy followed grounded theory approach since it offers a step-by-step, systematic procedure for analyzing qualitative data (Strauss and Corbin, 1998). Grounded theory can be used to study process, or looking for explanation of a process (Creswell 2007), which is what the second research question is all about.

Qualitative analysis is used to answer the second research question. Of this, there are four research sub-questions. The four sub-questions of inquiries are:

i. How does the CPBL model develop problem solving elements in students?
ii. How does the CPBL model improve students' motivation and their learning strategies?
iii. How does the CPBL model enhance effective team working among students?
iv. How does the CPBL model increase students' problem solving assets?

In this qualitative approach the research questions focused on the CPBL approach, on students describing their experiences mainly through interviews and reflection journals and on the students' tests and final examination papers. The CPBL approach consists of the CPBL cycles and problems organization. Students' reflect upon their works at the end of every problem they solved. Researcher interviewed several students at the end of the semester. The students' reflections and the interviews are analyzed using NVivo 8 and themes emerged from the reflections and interviews are analyzed. Samples of tests answer sheets and final examination papers are studied to see the improvement in the students' thinking process in terms of their problem solving abilities. In this study, the researcher's role is like an "instrument" through which the reality of the students' problem solving skills enhancement is explored. The researcher's presence is acknowledged, both by the students and the lecturer, and the engagement to the study is considered as an asset to the development of engineering education research.

3.6.1 Technical Characteristics

The reliabilities of the emerged themes in the reflection journals and interviews are conducted using Cohen's Kappa (Cohen 1960; Fleiss, 1981). The formula used in the analysis is as follows:

$$K = \frac{f_a - f_c}{N - f_c}$$

Where:

f_a = frequency of agreed

f_c = 50% expected agreed

N = Numbers of themes tested

Samples of coding and its' respected themes are given to three (3) experts for the reliability analysis. The three experts are the CPBL expert, the problem solving expert, and the qualitative analysis expert. The results of the analyses are shown in Table 3.7. According to Landis and Kosh (1977), if index Cohen's Kappa (K) is greater than 0.81, the reliability of the themes are considered as very high. The results of the analyses show that the themes are highly reliable, and thus, can be applied in the analysis.

Table 3.7: Reliability analysis for qualitative studies

	CPBL Expert	**Problem Solving Expert**	**Qualitative Study Expert**	**Average**
Problem Solving Elements	100	84.6	100	0.95
Motivation and Learning	100	100	100	1.00
Team Working	100	81.8	100	0.94
Problem Solving Assets	100	76	100	0.92

3.7 Data Collection

There are two sets of data collected in this study. One is used for pilot study and the other one is used for the actual research. Data for pilot study is used for two reasons, one is for primary investigation of the research and the other one is for conducting instrument's reliability test. Data for the actual research is used for investigating the solutions to the research questions.

Apart from the two sets of data, there are two types of data. One is for quantitative analysis and the other one is for qualitative analysis. The quantitative analysis data is used to find answer to the first research question, while the qualitative data is used to propose solutions to the second research question.

3.7.1 Pilot Study

Pilot study was done for two reasons: (1) as a primary investigation of the research, and (2) to develop and validate instrument required in the research. The primary investigation of the study consists of meta-analysis, familiarization of the CPBL approach, and conducting simple test related to issues of CPBL implementation. The meta-analysis is discussed in Chapter 2. The CPBL approach and the simple test are discussed in Chapter 4. In the instrument development and validation, the developed instrument was given to students for testing and comments. There were three classes, which consists of 120 students involved in the instrument development and validation. All the students took the same subject and taught by three different lecturers using CPBL approach. The designed instrument was validated by an experts in problem solving and problem-based learning.

3.7.2 Quantitative and Qualitative Data

The quantitative data are obtained by survey method using questionnaires. Based upon meta-analysis and the pilot study, three quantitative instruments are required:

i. Motivation and learning strategies
ii. Teamwork effectiveness, and
iii. Engineering problem solving.

There are available instruments that can be used for the first two, which are the MSLQ by Pintrich and his colleagues (1993) and TWES, by Imbrie and his colleagues (2005). However, for the third, there isn't any available instrument which can be used. The closest are problem solving inventories (for example: Heppner and Petersen, 1982) and general problem solving assessment tool (for example: Carter, et. al., 1986), which are not meant for evaluating engineering problem solving enhancement for students' undergone inductive learning methods, such as CPBL. Thus it was developed and named as the Engineering Problem Solving Instrument (EPSI). These instruments were given to all the students in the class at the beginning and at the end of the semester. All these data were analyzed using SPSS 18.0.

Qualitative data are obtained by observing the classroom and analyzing data taken form:

i. Selected students' reflection journals,
ii. Researcher's interviews on the students, and
iii. The students' tests and final exam answer scripts.

There are seven students (participants) directly involved in gathering these qualitative data. Their series of reflection journals were reviewed, and their test and final exam were analyzed. At the exit point of the course, they were interviewed using the prepared semi-structured questions (see Appendix J). All these sources were then analyzed with the aid of Nvivo 8.

3.7.3 Timeline for Data Collection

Figure 3.3 shows the timeline of the quantitative and qualitative data gathering process for the actual research study. At the beginning of the semester, pre-tests were given to all students in the selected class. Pre-tests consist of EPSI, MSLQ and TWES test instruments. Altogether, there are a total of 30 students in the class that consists of 9 groups. Based on the pre-test MSLQ result, the best and the worst groups (in terms of their cumulative motivation and learning strategies scores) were selected as participants for the qualitative analysis, to accommodate the two extreme conditions of the students' motivation and learning strategies.

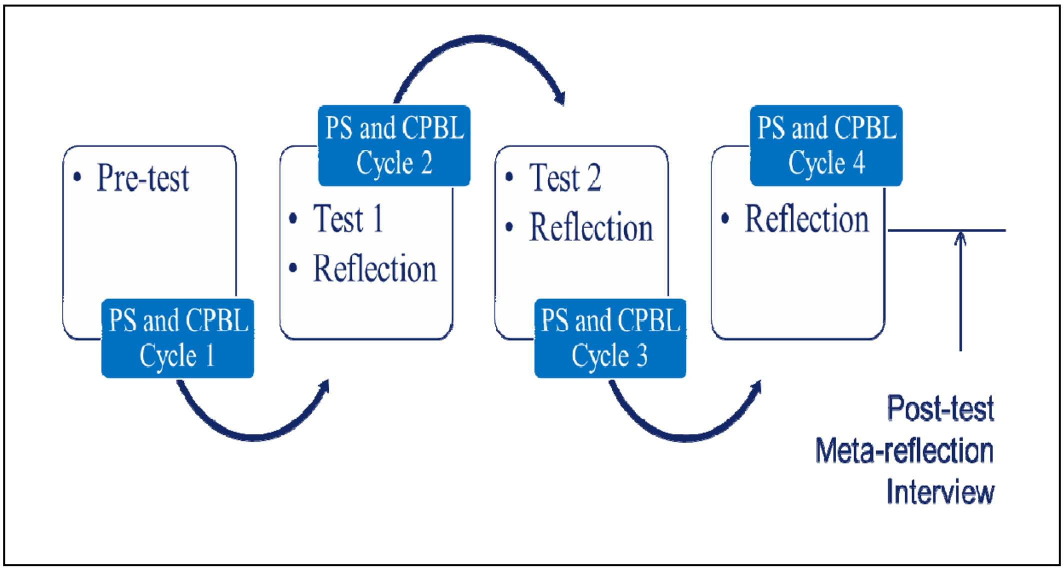


Figure 3.3: Timeline for data gathering

There are four case studies given throughout the semester. This means that there are four problem solving cycles and four CPBL cycles. At the end of every cycle, students reflected their problem solving process in their reflection journals. All the participants' reflection journals were analyzed. At the end of cycle 2 and cycle 3 students sit for test 1 and test 2 respectively, followed by the final examination at the end of the semester. All the tests and final exam questions that required deep understandings were analyzed, and the tests and final exam performances of the participants that required deep understanding were evaluated. Towards the end of the semester all the students in the class were given post-tests on EPSI, MSLQ and TWES which were used to quantitatively compare with the pre-tests given at the beginning of the semester. Along this time, the selected participants were interviewed to see how they perceived their study based on the CPBL approach particularly in the enhancement of their problem solving skills throughout the semester.

3.8 Data Analysis

Data are analyzed using both, quantitative and qualitative methodologies. The quantitative data is used to analyze and answer the first research question. The data obtained are analyzed using the latest version SPSS 18.0 software. The qualitative data is used to analyze and find solutions to the second research question. The qualitative data are documented, transcribed and analyzed using the NVivo 8.0 software.

3.8.1 Quantitative Data

The quantitative data are obtained by survey method using the three questionnaires mentioned above. They are the available MSLQ and TWES instruments, and the developed EPSI instrument. The purpose of using MSLQ, TWES and EPSI instruments are to evaluate the problem solving skills outcomes (or products) of the CPBL implementation. Pre-test and post-test were conducted to a selected class that consists of 30 students. The class was chosen based upon the readiness and experience of the lecturer in CPBL implementation. The My Readiness Inventory Questionnaire (MRIQ) by Woods (1996) is used to measure the readiness of the lecturer in conducting PBL class. (See Appendix A for the MRIQ instrument). The pre-test was given to all the students in the class at the beginning of the semester, and the post-test was given at the end of the semester. Table 3.8 summarizes constructs of the respective instruments given to the students.

Table 3.8: Summaries constructs for respective quantitative instruments

Quantitative Analysis	Constructs
EPSI (Helmi et al., 2011)	i. Problem Identification ii. Problem Analysis and Synthesis iii. Solution Generation iv. Reflection v. Self-directed Learning (based upon knowledge, confidence and process)
MSLQ (Pintrich et al., 1990)	i. Intrinsic Goal Orientation ii. Extrinsic Goal Orientation iii. Task Value iv. Control Belief about Learning v. Self-Efficacy for Learning and Performance vi. Test Anxiety
TWES (Imbrie et al., 2005)	i. Interdependency ii. Potency iii. Goal Setting

The EPSI measured the scores of deep learning for each construct, by comparing the deep learning scores at the beginning of the semester with the score at the end of the semester. The MSLQ and TWES measure the scores of students' motivation and learning strategies constructs, and team working effectiveness constructs, by comparing the scores at the beginning and the end of the semester. The results were analyzed to find answer to the first question of the research. Table 3.9 summarized the measures used in the analysis, data analysis and techniques, and nature of the expected results from the quantitative analyses.

Table 3.9: Summary of the measures, data analysis and techniques, and results of the respected quantitative analyses

Method	Measures	Data analysis and Techniques	Result
Self-Developed Engineering Problem Solving Instrument	Significance increment in deep understanding in problem solving	Paired t-test (Pre-post)	Total scores and Percentage Increased
Motivation and Learning Strategies Questionnaire	Significance increment in motivation and learning strategies	Paired t-test (Pre-post)	
Team Working Effectiveness Scores	Significance increment in team effectiveness	Wilcoxon Signed Ranks Test (pre-post)	

3.8.2 Qualitative Data

Qualitative data are obtained through observations, documents analyses, by analyzing selected students' reflection journals, researcher's interviews on the students, and the students' tests and final exam answer scripts. Observation was done in the selected class to analyze the CPBL process. All the related documents used in the class were gathered and analyzed, especially the case studies. As for the participants in the qualitative research, they were selected based upon the pre-test result of the MSLQ score. There were a total of seven students in two selected heterogeneous groups. At the end of every case study students reflected upon their works in their reflection journals. While at the end of the semester students did meta-reflections. All these series of reflection journals and meta-refection journals are reviewed to see the ways the participants enhanced the problem solving skills. At the end of the semester, all the seven participants were interviewed based upon semi-structured questions prepared. Their tests and final exam papers were critically reviewed and studied to see patterns of enhancement in the students' higher order thinking, thus, their problem solving skills, as suggested by Woods (2000). Table 3.10 summarized the constructs, the measure, the data analysis and technique used and the expected results of the qualitative analysis. (See Appendix B for the 4 case studies given to the students, see Appendix K for sample of student's reflection journal, and Appendix J for semi-structured questions asked during the interview).

Table 3.10: Summary of the constructs, measures, data analysis and technique, and result of qualitative analysis

Method	Construct	Measure	Data analysis and Techniques	Result
Observation and Documents, Reflection Journals, Interviews, and Tests and Final exam Answer Scripts	CPBL process, Emerging themes and test answer scripts interpretation	CPBL approach, Sub-models development (axial, and selective coding), deep understanding assessments	Grounded theory approach, perception of problem solving enhancement.	Rich text explanations, triangulation, proposed model

Both direct and indirect assessments to gauge the students' problem solving process and its' related factors are used. For the first research question, important factors that influenced students' problem solving skills such as team working skills, students' motivation are observed and analyzed, apart from the elements of problem solving. For the second research question, problem solving skills are examined using reflection journals, interviews, and reviews of students' test answer scripts. Table 3.11 summarized the elements understudied, its' coverage and the way of assessing.

3.9 Conclusion

This chapter described the methodology employed in this research. Overview of the methodology, research design, research framework, subject of the study, instruments selection and development, data collection and analysis. In the next chapter, the detailed findings of the research are presented.

Table 3.11: Assessing quantitative and qualitative analyses

		Coverage	Direct	Indirect
First Research Questions (Quantitative Analysis)	Problem Solving Elements	Whole Class		√
	Team Working Skills	Whole Class		√
	Students' Motivation	Whole Class		√
Second Research Question (Qualitative Analysis)	Students' Reflection Journals	7 students		√
	Students' Tests Answer Scripts	7 students	√	
	Researcher's Interviews	7 students		√

CHAPTER 4

DATA GATHERING AND ANALYSIS

4.1 Introduction

This chapter explains data gathering and analysis of the research that investigates and finds answer to the following questions: (1) To what extent the Cooperative Problem-Based Learning (CPBL) approach enhance problem solving skills among engineering students? (2) How does the approach develop problem solving skills in students?

As mentioned in the conclusion of Chapter 2, understanding the enhancing problem solving skills through CPBL involved four important attributes: (i) students' problem solving elements; (ii) students' motivation and learning strategies; (iii) team working effectiveness; and (iv) students' problem solving assets.

The first research question is quantitatively studied by examining six sub-questions. The second research question is investigated deeper through qualitative approach. The questions are addressed in sequence, starting by using quantitative analysis followed by qualitative analysis.

4.2 Research Question 1: Quantitative Analysis

There are six research sub-questions for the first research question. These research sub-questions are very much in line with those recommended by Barrows and Kelson (1995) as mentioned in Chapter 2. They are:

i. Do students become better problem-solvers in terms of its processes?
ii. Do students improve their ability to reflect the process they went through in solving problems?
iii. Do students become better self-directed learners by engaging in solving problems?
iv. Do students improve their learning motivation and their employment of learning strategies through CPBL that will enhance their problem solving skills?
v. Do students improve their team working skills by solving problems cooperatively in CPBL which lead to enhancement of their team-based problem solving skills?
vi. Do students become better problem solvers in terms of acquiring their problem solving assets through CPBL?

All the six sub-questions are answered using the designed Engineering Problem Solving Instrument (EPSI), the Pintrich's (1990) Motivated Strategy for Learning Questionnaire (MSLQ) and the Imbrie's et al. (2005) Team Working Effectiveness Score (TWES) as discussed is Chapter 3. The findings are analyzed using SPSS 18 as reported in this chapter. The results of the findings are discussed in detail in Chapter 5.

The first three sub-questions are analyzing the attributes of problem solving elements, the fourth and fifth sub-questions are examining the students' motivation and learning strategies and team working effectiveness, respectively. The sixth sub-question is exploring the students' problem solving assets.

4.2.1 Engineering Problem Solving Elements

The impact of CPBL on problem solving elements are analyzed using the developed Engineering Problem Solving Instrument (EPSI) to measure improvements in the elements as perceived by engineering students upon going through a course using CPBL methodology as detailed out in Chapter 3. It compared the deep thinking approach before and after the students went through CPBL course.

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

As shown in Figure 4.1, at the beginning of the semester the students' deep thinking scores at all levels of engineering problem solving processes, reflection and self-directed learning are far lower than the scores at the end of the semester.

Regarding this, Table 4.1 shows percentage increase in the scores of deep thinking which are based upon the students' perception at the beginning of the semester and at the end of the semester, as abstracted from the EPSI survey. As shown in the table, deep thinking of students' reflection increased the most, followed by students' self-directed learning. The students' problem solving process increased about the same, which is around 30%. Figure 4.2 shows percentage improvement of the problem solving elements.

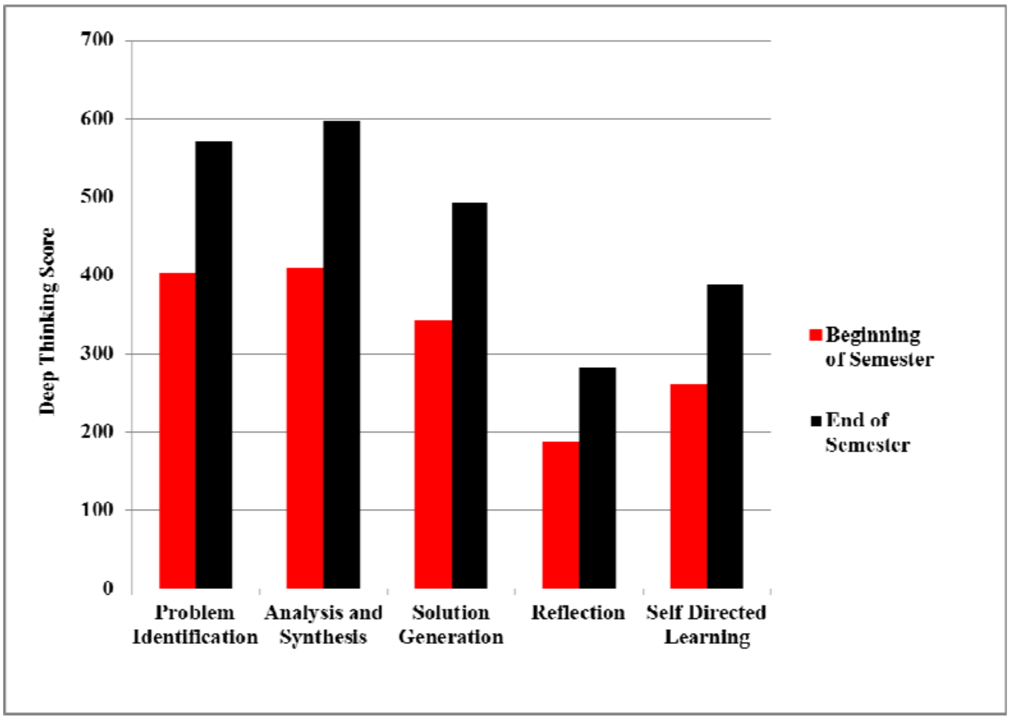


Figure 4.1: Deep thinking of engineering problem solving elements

Table 4.1: Percentage increased in deep thinking of problem solving elements

	Deep Thinking (% increased)
Problem Identification	29
Analysis and Synthesis	31
Solution Generation	30
Reflection	34
Self Directed Learning	33

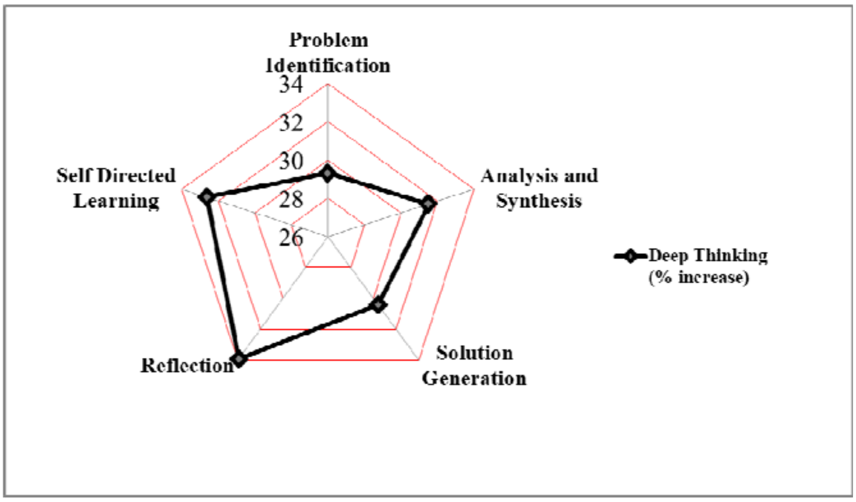


Figure 4.2: Increased of students' deep thinking of problem solving elements

This can also be explained through comparing mean values of statistical data using paired sample t-test. Since all skewness and kurtosis ratio of the data are within +2 and -2, they are normally distributed (see Appendix L for detail). Thus, they can be analyzed using parametric analysis.

The result of paired sample statistic is shown in Table 4.2. The mean values for deep thinking at all level of problem solving processes, reflection and self-directed learning, have increased at the end of the semester compared to the beginning of the semester. As shown in Table 4.2 and Table 4.3, the paired sample t-test illustrated that there are significant differences of all the means in deep thinking of the students' problem solving elements, at the beginning compared to at the end of the semester for CPBL class. Referring to Table 4.4, the t-test result are; $t(29)_{\text{Problem Identification}} = 8.86$; $p<.05$, $t(29)_{\text{Problem Analysis and Synthesis}} = 8.89$; $p<.05$, $t(29)_{\text{Solution Generation}} = 9.68$; $p<.05$, $t(29)_{\text{Reflection}} = 10.02$; $p<.05$, and $t(29)_{\text{Self-Directed Learning}} = 7.42$; $p<.05$. As shown in Table 4.4, the effect sizes (d) for all the comparison are also greater than 0.8.

Table 4.2: Paired sample statistic for engineering problem solving elements

	Mean (Deep Thinking)	**Std. Deviation**	**Std. Error Mean**
Problem Identification			
Beginning of Semester	13.43	3.520	.643
End of Semester	19.00	2.600	.475
Analysis and Synthesis			
Beginning of Semester	13.63	3.102	.566
End of Semester	19.90	2.881	.526
Solution Generation			
Beginning of Semester	11.43	3.234	.591
End of Semester	16.43	2.079	.380
Reflection			
Beginning of Semester	6.23	2.239	.409
End of Semester	9.43	1.755	.321
Self-directed Learning			
Beginning of Semester	8.73	2.912	.532
End of Semester	12.97	1.974	.360

4.2.2 Students' Motivation and Learning Strategies

The impact of CPBL on students' motivation and learning strategies on solving problems are analyzed using Motivation Strategies and Learning Questionnaire (MSLQ) developed by Pintrich (1990). The instrument is used to measure students' motivation and learning strategies as perceived by engineering students upon going through CPBL in a course. Only MSLQ constructs that are suitable for the study are used in the analysis. The analysis is used to quantitatively answer the following question: Do students improve their learning motivation and their employment of learning strategies that will enhance their problem solving skills?

Table 4.3: Paired sample t-test for engineering problem solving elements

		Paired Differences				t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
		Std. Deviation	Std. Error Mean	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 4.4: Paired sample test result and its effect for engineering problem solving ability

	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

The learning motivation section is divided into two components: value and expectancy. Value component measures students' goal orientations and value beliefs for the course. It contains three scales: intrinsic goal orientation, extrinsic goal orientation, and task value. As shown in Table 4.5, intrinsic and task value scores have increased towards the end of semester, however the extrinsic score has slightly decreased. Expectancy component measures students' expectancy for success in a course. In the result, the students' control of learning beliefs has increased.

Table 4.5: Motivation and learning strategies

			Beginning of Semester (Score)	End of Semester (Score)
Learning Motivation	Value	Intrinsic Goal Orientation	16.01	22.37
		Extrinsic Goal Orientation	21.27	19.60
		Task Value	27.73	35.20
	Expectancy	Control Beliefs about Learning	20.53	23.90
Learning Strategies	Cognitive and Meta-cognitive	Organization	15.83	21.13
		Critical Thinking	19.00	27.43
	Resource Management	Effort Regulation	17.67	21.20
		Help Seeking	16.40	20.57

The learning strategies section is divided into two components: (1) Cognitive and Meta-cognitive Strategies, and (2) Resource Management Strategies. Cognitive and meta-cognitive strategies component measures students' use of cognitive and meta-cognitive strategies. In this study, the organization and critical thinking scores has increased. Organization refers to making connections between content to be learned while critical thinking involves making evaluations and applying prior knowledge to new contexts for solving problems. Resource management strategies component measures students' use of resource management strategies. In this study the effort regulation and help seeking scores are also increased by the end of semester. In summary, all the scales for learning motivation and strategies have increased by end of semester, except the students' extrinsic value has slightly decreased. This is also shown in Figure 4.3.

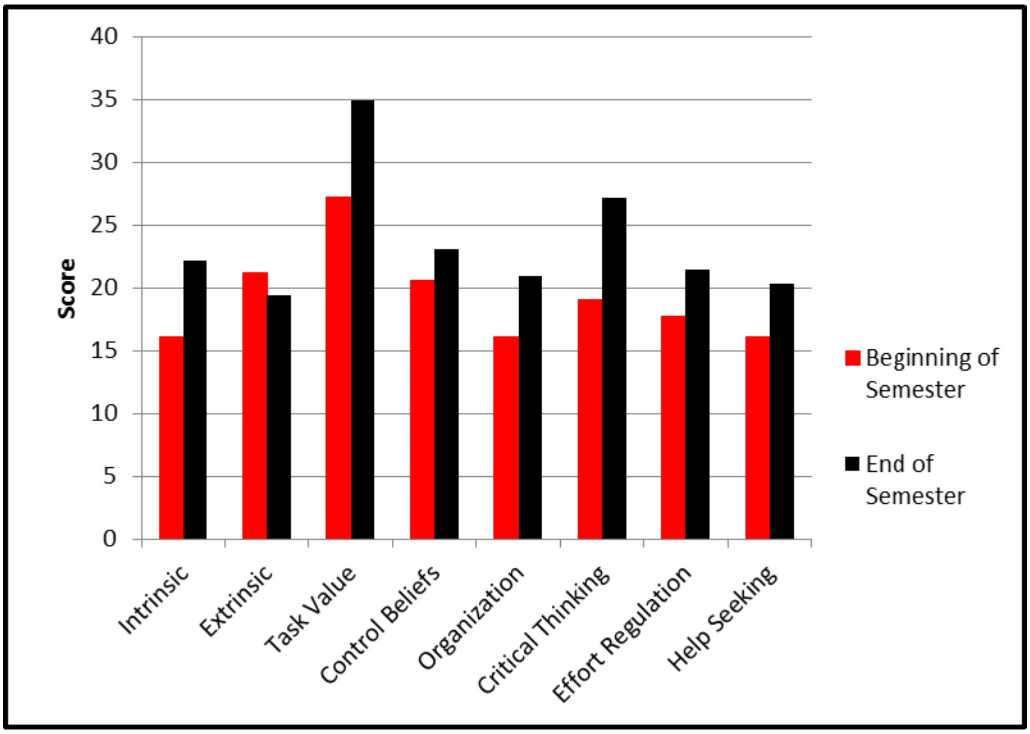


Figure 4.3: Comparing students' motivation and learning strategies

Table 4.6 shows percentage increase in the students' motivation and learning strategies scores which are based upon the students' perception at the beginning of the semester and at the end of the semester, as abstracted from the EPSI survey. As shown in the table, students' critical thinking score increased the most, at around

40%, followed by 38% increase in students' intrinsic goal orientation. The students' extrinsic goal orientation score decrease at around 8%. Figure 4.4 illustrated percentage improvement of the motivation and learning strategies.

This is also explained through comparing mean values of statistical data using paired sample t-test. Since all skewness and kurtosis ratio are within +2 and -2 (see Appendix L for detail), all data are normally distributed, and can be analyzed using parametric analysis.

Table 4.6: Pecentage increased in students' MSLQ scores

	% Difference
Intrinsic Goal Orientation	38
Extrinsic Goal Orientation	-8
Task Value	28
Control Beliefs about Learning	12
Organization	30
Critical Thinking	42
Effort Regulation	21
Help Seeking	26

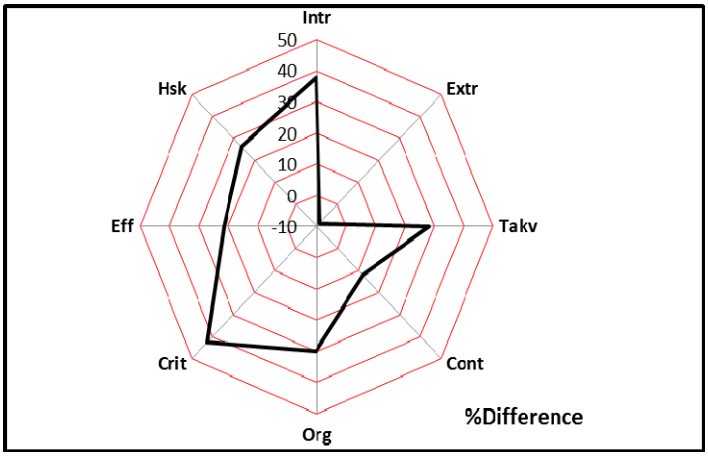


Figure 4.4: Percentage difference in MSLQ scores

The result of paired sample statistic is shown in Table 4.7. The mean values at the end of the semester are higher than at beginning of semester for all measures, except extrinsic goal orientation. As shown in Table 4.8 and Table 4.9, the paired sample t-test illustrated that there are significant differences of all the means in students' learning motivation and strategies, at the beginning as compared to at the end of the semester for CPBL class. In summary, the t-test results are:

- $p<.05$; $t(29)_{Intrinsic} = -7.199$;
- $p<.05$; $t(29)_{Extrinsic} = 2.520$;
- $p<.05$; $t(29)_{Task\ Value} = -6.359$;
- $p<.05$; $t(29)_{Control\ Belief} = -4.863$;
- $p<.05$; $t(29)_{Organization} = -7.351$;
- $p<.05$; $t(29)_{Critical\ Thinking} = -8.142$;
- $p<.05$; $t(29)_{Effort} = -4.750$;
- $p<.05$; $t(29)_{Help\ Seeking} = -6.010$.

These values show that the mean values for students' motivation and learning strategies are significantly higher at the end of the semester compared to at the beginning of the semester for all the measures except the extrinsic goal orientation. As shown in Table 4.8, the effect sizes (d) for all the comparison are also greater than 0.8. However, the effect size of extrinsic goal orientation is smaller than 0.5. According to Cohen (1988), effect sizes greater than 0.8 have great effect in the study, but lower than 0.5 has a small effect.

Table 4.7: Paired sample statistic on motivation and learning strategies

	Mean	**Std. Deviation**	**Std. Error Mean**
Intrinsic			
Beginning of Semester	16.067	5.330	0.973
End of Semester	22.367	2.684	0.490
Extrinsic			
Beginning of Semester	21.267	3.704	0.676
End of Semester	19.600	4.391	0.802
Task Value			
Beginning of Semester	27.733	6.324	1.155
End of Semester	35.200	3.969	0.725
Control Belief			
Beginning of Semester	20.533	4.091	0.747
End of Semester	23.900	2.551	0.466
Organization			
Beginning of Semester	15.833	4.526	0.826
End of Semester	21.133	3.014	0.550
Critical Thinking			
Beginning of Semester	19.000	5.427	0.991
End of Semester	27.433	2.825	0.516
Effort			
Beginning of Semester	17.667	4.452	0.813
End of Semester	21.200	3.418	0.624
Help Seeking			
Beginning of Semester	16.400	3.971	0.725
End of Semester	20.567	2.208	0.403

Table 4.8: Paired sample test on motivation and learning strategies

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Intrinsic – Beginning of Semester - End of Semester	-6.300	4.793	.875	-8.090	-4.510	-7.199	29	.000
Pair 2	Extrinsic – Beginning of Semester - End of Semester	1.667	3.623	.661	.314	3.020	2.520	29	.018
Pair 3	Task Value – Beginning of Semester - End of Semester	-7.467	6.431	1.174	-9.868	-5.065	-6.359	29	.000
Pair 4	Control Belief – Beginning of Semester - End of Semester	-3.367	3.792	.692	-4.783	-1.951	-4.863	29	.000
Pair 5	Organization – Beginning of Semester - End of Semester	-5.300	3.949	.721	-6.775	-3.825	-7.351	29	.000
Pair 6	Crit. Thinking – Beginning of Semester - End of Semester	-8.433	5.673	1.036	-10.552	-6.315	-8.142	29	.000
Pair 7	Effort – Beginning of Semester - End of Semester	-3.533	4.075	.744	-5.055	-2.012	-4.750	29	.000
Pair 8	Help Seeking – Beginning of Semester - End of Semester	-4.167	3.797	.693	-5.585	-2.749	-6.010	29	.000

Table 4.9: Paired sample test and effect size on motivation and learning strategies

	Paired Differences			t	p< .05	Effect Size (d)
	Mean	Std. Deviation	Std. Error Mean			
Intrinsic	-6.300	4.793	.875	-7.199	Sig	1.49
Extrinsic	1.667	3.623	.661	2.520	Sig	0.41
Task Value	-7.467	6.431	1.174	-6.359	Sig	1.41
Control Belief	-3.367	3.792	.692	-4.863	Sig	0.99
Organization	-5.300	3.949	.721	-7.351	Sig	1.38
Critical Thinking	-8.433	5.673	1.036	-8.142	Sig	1.95
Effort Regulation	-3.533	4.075	.744	-4.750	Sig	0.89
Help Seeking	-4.167	3.797	.693	-6.010	Sig	1.30

4.2.3 Team Working Effectiveness

The impacts of CPBL on team working elements are analyzed using both quantitative and qualitative analyses. For quantitative analysis, the Team Working Effectiveness Score (TWES) was used to measure improvements in team effectiveness as perceived by engineering students upon going through a course using CPBL methodology.

For quantitative analysis, three elements are considered in the study, which are (1) interdependence, (2) potency, and (3) goal setting. As shown in Table 4.10, all the three elements score higher at the end of semester as compare to the beginning of the semester. Figure 4.5 shows the description of the score.

Table 4.10: Team working effectiveness scores

	Beginning of Semester	End of Semester
Interdependent	33.5	35.6
Potency	19.3	20.7
Goal Setting	16.6	18.7

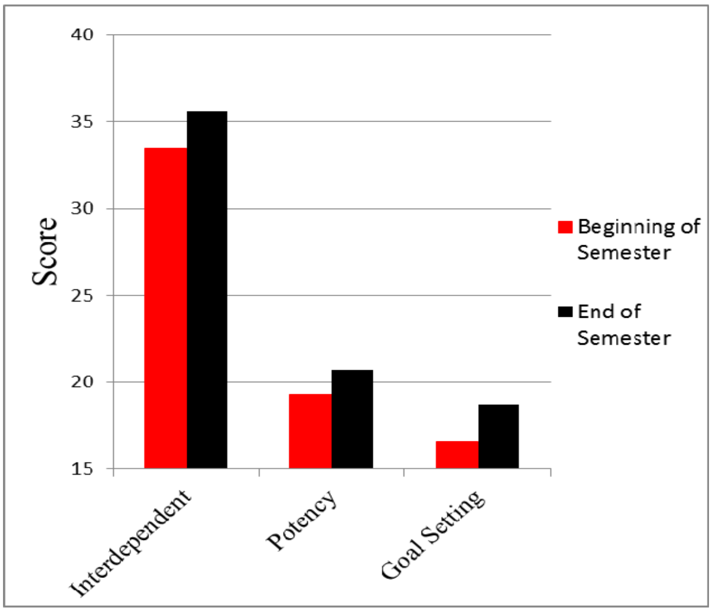


Figure 4.5: Comparing students' team effectiveness scores

Table 4.11 shows percentage increase in the scores of team effectiveness which are based upon the students' perception at the beginning of the semester and at the end of the semester, as abstracted from the TWE survey. As shown in the table, students' goal setting increased the most which is around 13%. Figure 4.6 shows percentage improvement of team effectiveness which obviously indicates that students' goal setting increased the most, followed by potency and interdependency, respectively.

Table 4.11: Percentage increased in students' TWES scores

	% Increased
Interdependent	6
Potency	7
Goal Setting	13

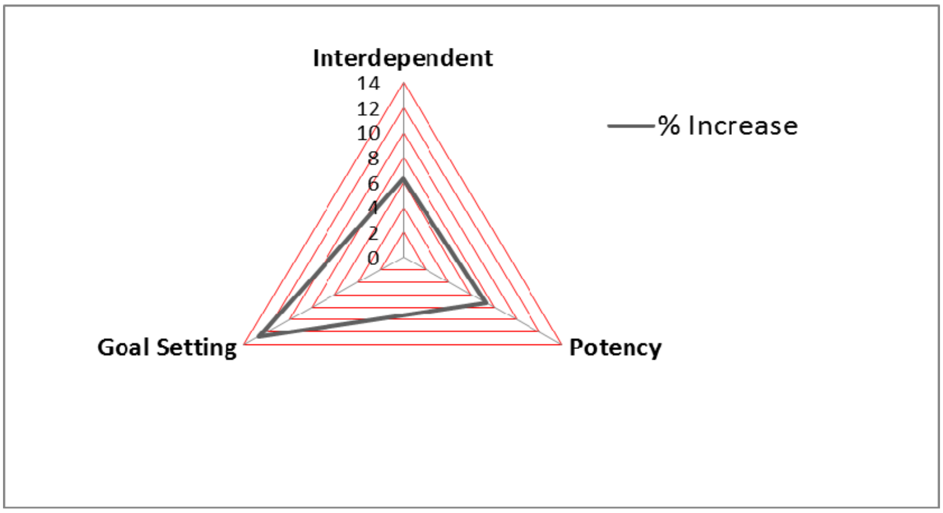


Figure 4.6: Percentage increased in TWES scores

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 kurtosis ratio for potency are very high, especially at the end of semester (see Appendix L for detail). 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 4.12 and Table 4.13 show the result of the test.

Table 4.12: Descriptive statistic 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 4.13: Wilcoxon signed ranks test and effect sizes

		z	N	Sig. (2-tailed)	p< .05	Effect Size (r)
Pair 1	Interdependent– Beginning of Semester - End of Semester	-2.058	60	.040	Sig	-0.265
Pair 2	Potency – Beginning of Semester - End of Semester	-2.270	60	.023	Sig	-0.293
Pair 3	Goal Seeking – Beginning of Semester - End of Semester	-2.373	60	.018	Sig	-0.306

Wilcoxon analysis is used to determine if there any differences in team effectiveness elements at the beginning of semester and at the end of the semester. The study shows that there are significant difference of all the team effectiveness elements between the beginning and the end of the semester. The results are as follow:

- Interdependency:
  $Md_{\text{beginning of semester}}$ =35.5, $Md_{\text{end of semester}}$ =36, $z = -2.058$, $p<.05$, $r =-0.265$;
- Potency:
  $Md_{\text{beginning of semester}}$ =19.5, $Md_{\text{end of semester}}$ =21, $z = -2.270$, $p<.05$, $r=-0.293$;
- Goal Seeking:
  $Md_{\text{beginning of semester}}$ =16.5, $Md_{\text{end of semester}}$ =19, $z = -2.373$, $p<.05$, $r=-0.306$).

All the effect sizes (r) are around 0.3. According to Cohen (1988), effect sizes greater than 0.3 in Wilcoxon statistical analysis are considered as large. Therefore, the test shows that there are significant differences between team effectiveness in terms of the students' interdependency, potency and goal seeking, where students' team working are significantly more effective at the end of the semester compared to the beginning of the semester.

4.2.4 Engineering Problem Solving Assets

The impacts of CPBL on problem solving assets are analyzed using both quantitative and qualitative analyses. For quantitative analysis, the developed Engineering Problem Solving Instrument (EPSI) was used to measure improvements in problem solving assets as perceived by engineering students upon going through a course using CPBL methodology.

Do students improved their problem solving assets which are: knowledge, confidence and cognitive process? As shown in Figure 4.7, at the beginning of the semester, the students' deep thinking scores are far lower than the scores at the end of the semester. This indicates that the students' deep thinking had improved as a result of their learning based on CPBL.

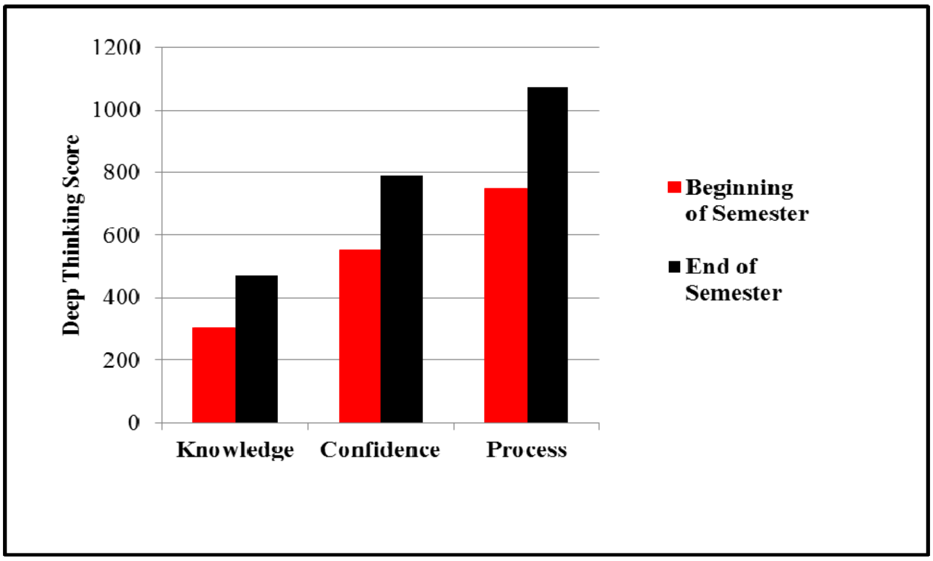


Figure 4.7: Deep thinking of engineering problem solving assets

Table 4.14 shows the percentage increased in the scores of deep thinking which is based upon the students' perception towards themselves at the beginning of the semester and at the end of the semester, as abstracted from the EPSI survey. As shown in the table, knowledge element has the highest percentage increased in deep thinking. Figure 4.8 shows the degree of improvement in the students thinking. The figure shows that the students' deep thinking has improved more especially the students' knowledge.

Table 4.14: Percentage increased in deep thinking on problem solving assets

	Deep Thinking (% increased)
Knowledge	35
Confidence	30
Process	30

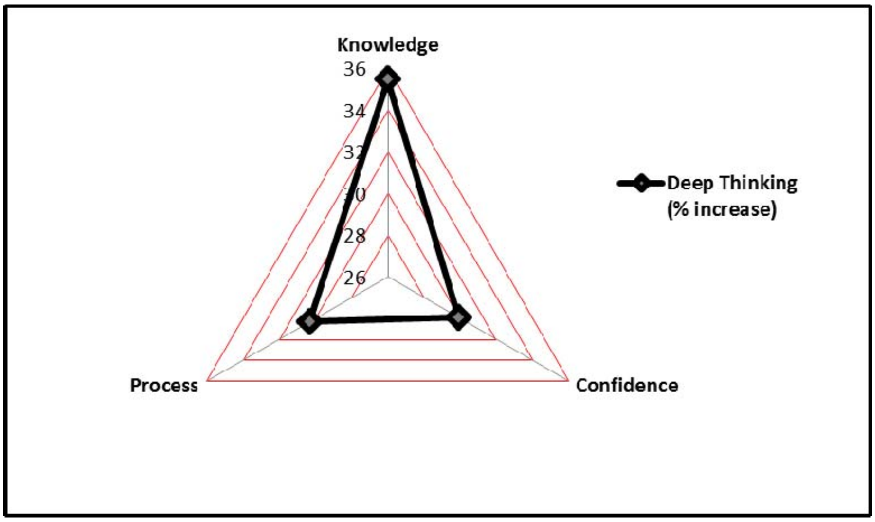


Figure 4.8: Increased of students' deep thinking on engineering problem solving assets

This is also explained through comparing mean values of statistical data using paired sample t-test. Test for normality shows that all skewness ratios and kurtosis ratio are within +2 and -2 (see Appendix L for detail). Thus, all data are normally distributed, and can be analyzed using parametric analysis.

The result of paired sample statistic is shown in Table 4.15. The mean values for deep thinking of all students' problem solving assets at the end of the semester have the highest scores as compare to the beginning of the semester. As shown in Table 4.16 and Table 4.17, the paired sample t-test illustrated that there are significance difference of all the means in deep thinking of students' knowledge, confidence and process, at the beginning as compared to at the end of the semester for CPBL class.

Table 4.15: Paired sample statistic on engineering problem solving assets

	Mean Scores of Deep Thinking	Std. Deviation	Std. Error Mean
Knowledge			
Beginning of Semester	10.13	3.224	.589
End of Semester	15.70	2.548	.465
Confidence			
Beginning of Semester	18.43	4.861	.888
End of Semester	26.30	4.044	.738
Process			
Beginning of Semester	24.90	6.189	1.130
End of Semester	35.73	4.017	.733

Table 4.16: Paired sample test on engineering problem solving assets

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	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

In summary, the t-test result are; $t(29)_{Knowledge}$ =11.402; p<.05, $t(29)_{Confidence}$ =8.615; p<.05, and $t(29)_{Process}$ =9.898; p<.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 of the semester for knowledge, confidence and process. As shown in Table 4.17, the effect sizes for all the comparison are also greater than 0.8. According to Cohen (1988), effect sizes (d) greater than 0.8 have great effect in the study.

Table 4.17: 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
Confidence	7.87	5.002	.913	8.615	Sig	1.76
Process	10.83	5.995	1.094	9.898	Sig	2.08

4.3 Research Question 2: Qualitative Analysis

There are four research sub-questions for the second research questions. The four sub-questions of inquiries are:

(1) How does the CPBL model develop problem solving elements in students?

(2) How does the CPBL model improve students' motivation and their learning strategies?

(3) How does the CPBL model enhance effective team working among students?

(4) How does the CPBL model increase students' problem solving assets?

The reasons behind the answers to the questions are qualitatively studied. NVivo 8 software is used to ease the analyses. The themes emerged are validated by experts in problem solving, CPBL methodology, and qualitative analysis. The findings of the analysis are reported in this chapter. The results of the analysis are presented in Chapter 5. The discussion starts with the description of the CPBL approach, followed by the analyses to find answers to the questions above.

4.3.1 The Cooperative Problem-Based Learning (CPBL) Approach

The original PBL framework implemented in UTM-PBL, modified from Tan (2003), contains the typical PBL cycle, as described in Chapter 2. However, rather than having small tutorial groups of up to 10 students, the whole cycle is implemented on small groups of 3 to 4 students, in a class of up to 60 students, which is the typical engineering class size in Universiti Teknologi Malaysia (UTM).

Since supporting and monitoring students' learning by a floating facilitator can be challenging in a typical class of up to 60 students, the CL aspects is integrated in the approach to encourage cooperation and peer-based learning as well as monitoring and support, thus becoming Cooperative Problem Based Learning (CPBL).

From the UTM-PBL framework the approach evolves to the framework shown in Figure 4.9 to emphasize the importance of ensuring cooperative work among students in the small groups and the whole class (Mohd-Yusof and Helmi, 2008). Referring to the figure, there are 3 phases in the CPBL cycle. Phase 1 consists of the problem identification and analysis. Phase 2 is the learning, application and solution formulation stage. Phase 3 is the generalization, internalization and closure stage. This modification to the CPBL framework is necessary to ensure the learning activities and assessment tasks throughout the CPBL cycle is aligned and supported all the learning outcomes.

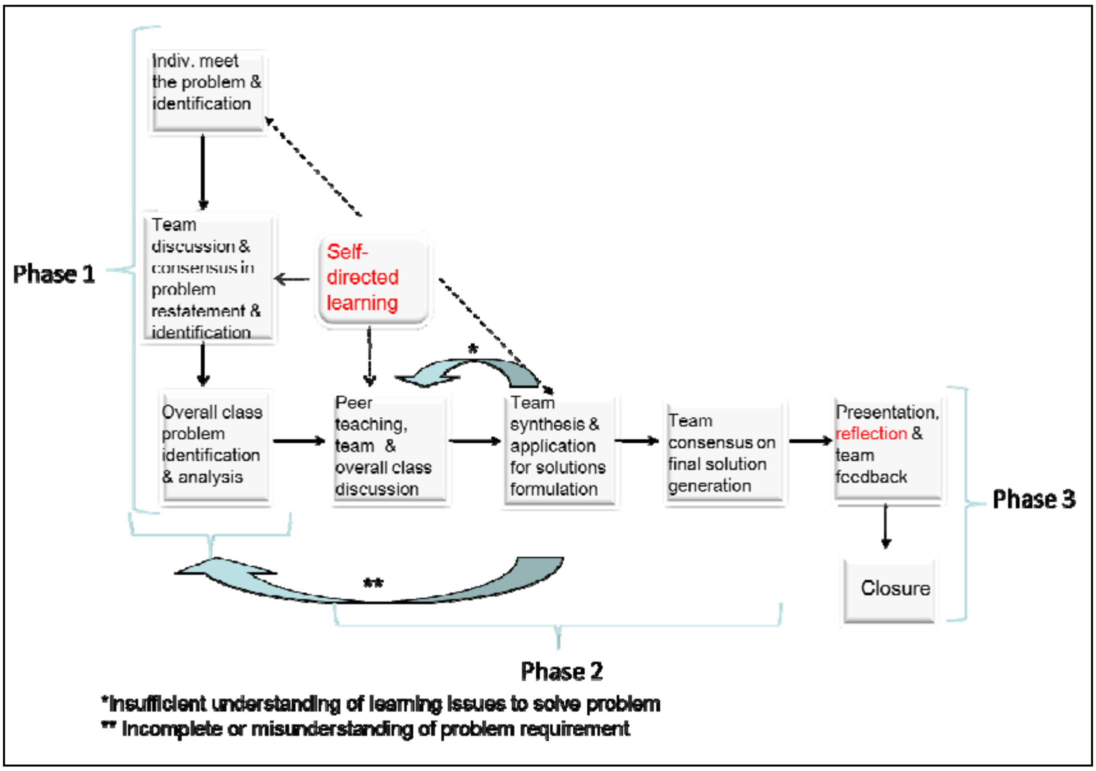


Figure 4.9: The cooperative problem-based learning (CPBL) framework

The five principles of cooperative learning are aligned to the learning activities throughout the CPBL cycle, as shown in Table 4.18, since ensuring cooperation and functional teams for students to learn together is crucial. As seen in the table, the important parts of problem solving skills enhancement are self-directed learning and team working. The students have to learn by themselves in order to solve the given problems in a team through peer teaching and group discussions. The learning process is given back to the students; and students learn with a purpose and out of curiosity to solve the problems.

Because of the complexity of the problems, through peer teaching, group discussion and overall class discussion, the students learned to motivate themselves and improve their learning strategies. Because it is not possible to monitor individual learning and all their discussions in small teams, the assessment delivered is aligned the learners' activities to provide feedback not only to lecturer, but also to students, on their progress towards achieving the desired outcomes. The assessment results are used to further decide on the kind of scaffolding needed by students.

Table 4.18: Incorporating CL principles in teaching and learning in CPBL (Mohd-Yusof, et al., 2010)

CL Principles		**Positive interdependence**	**Individual accountability**	**Face to face interaction**	**Interpersonal skills**	**Group function assessment**
Phase 1 Problem restatement & Identification	Individual	Prepare to discuss with team	Submit PR & PI before discussions			
	Team discussion & consensus	Consensus to bring to whole class; may submit team PR & PI; assign learning issues for each team member	Start discussion based on individual answer; agree on learning issues to read and learn by each member	In- class discussion; assign roles for each team member during duration of problem	Reach consensus within given time	Overall observation of participation and body language
	Overall class discussion	Each team provide opinion	Anyone may be randomly called	In- class discussion	Proper etiquette in discussion, Q&A to reach overall consensus	Observation of participation
Phase 2 Learning, application & solution	Peer learning	Notes contain summary of concepts understood and questions on hazy points to help learning in team; assume role play	Individually prepare peer learning /teaching notes for team; submit individual peer learning notes; role play	Learn in team – explain concepts understood and ask those still hazy; overall class peer learning/ teaching/ discussion led by designated team	Reach consensus on understanding of concepts or learning issues and questions to ask during in-class session	Observation of participation during overall class peer learning/ teaching/ discussion
	Synthesis & application	Quiz or tutorial questions on important concepts; e-learning forum	Quiz or tutorial questions on important concepts	Out-of class sessions	Out of class sessions	Progress check
	Consensus on final solution	Submit 1 report for each team	Optional quiz, test/exam	Out of class sessions	Out of class sessions	
Phase 3 Generalization, closure & internalization	Presentation, reflection, team rating & feedback	Comparison of solution between different teams in class	Individual feedback from team members on performance	Presentation of final solution and discussion led by designated team	Sincere comments to help team improve	Peer rating and feedback on team members and team process
	Closure	Generalize concepts to other types of problems	Internalize lessons learned from content and process through written reflection	In-class closure session	Motivation on team working & conflict management	In-class session on improvement to be made

Organization of Case Studies

The developments of all case studies were structured such that they brought students up to a higher level of expectation (Refer to Appendix B for all the case studies given). In the first case study, the scenario was corresponded to the current profile as third-year students who attended an interview session at a company to get a place for internship. The technical difficulty of the first case study covered the analysis of simple processes, classification of process variables and identification of basic control structures.

In the second case study, students took roles as trainees in a chemical plant at the company where they applied for internship as in the first case study. The technical difficulty was higher, as the problem covered mathematical modeling and analysis. In this case study students had to derive a dynamic model of a process in order to determine the dynamic response of a variable due to certain changes in the process.

In the third case study, the students were hired to work as graduates engineers in charge of process control of the same plant as in the previous case studies. The level of difficulty was higher than the second case study, where the students were required to perform experiments in the laboratory, or run dynamic simulation of the chosen process to perform model estimation, stability analysis and controller tuning.

Finally, in the fourth case study, the students became consultant engineers in a consulting firm. Here, the students had to design an automatic control system as part of a bidding effort for a section of a real chemical plant. Arrangement with a company was made ahead of time to get the process description. The students had the opportunity to visit the plant, where they asked questions for further information on the process. The simulated bidding event was held where students had poster presentation displaying their control system design. Lecturers, engineers and plant personnel from the company were invited to evaluate and judge the students' design. The best teams were given certificates from the company.

To provide explicit learning context to the students, problems designed were authentic and realistic. They represented the professional practices where learning issues resembled the working environment that students would possibly encounter in the actual practices. The problems required students to perform the same learning activities in the learning environment as they would in the actual workplace. The complexity of the problems was suitable enough to ensure participation and engagement in learning process, and thus promoted self-directed learning and lifelong learning. While solving the problem, it led students to a higher cognitive level where critical thinking and meta-cognition applied. This was in accordance to the constructive alignment principles (Biggs and Tang, 2010).

According to constructivist (Savery and Duffy, 1995) and SOLO taxonomy (Biggs and Tang, 2007), learning grows cumulatively in stages in which the learned content is increasingly complex. This was how problems in this CPBL course were arranged. As mentioned above, each problem was built upon the previous to develop and bring up students' cognitive ability as well as knowledge. In other words, learning issues for the problems were connected; the content learned in the previous problem became the basis for extending new knowledge needed for the current problem. Besides promoting deep learning for all learning outcomes, this approach helped the students to see that knowledge were not isolated, instead, integrated between one another and exist as a whole. Therefore the ability to reflect and generalize the knowledge learned was crucial.

Table 4.19 illustrates the design of the first case study in Process Control and Dynamics course. The case study was mapped to the five principles of designing effective engineering problems proposed. The table also acted as a checklist during problem crafting process. Case Study 1 was very simple as it only covered basic concepts of course, plus the duration for this particular case study was only one week. Therefore, not all principles of effective engineering problems could be met at this phase. Referring to the problem scenario, Polystyrene (M) Ptd. Ltd., a hypothetical petrochemical company was chosen to provide context to the problem.

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Table 4.19: Mapping of learning outcomes to the respected case studies (Jamaluddin et al., 2010).

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

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

As the learning outcomes were getting difficult and significant, demand at the workplace should be enhanced as well, for instance from simple task to a big project. It should correspond to the job specification of the assigned role as industrial practitioners. It was expected that after solving several problems through a series of CPBL cycles, students would transform from “novice” engineering problem solvers to “experts” within the course duration. This idea of organizing problems in a one-semester curriculum is shown schematically in Figure 4.10.

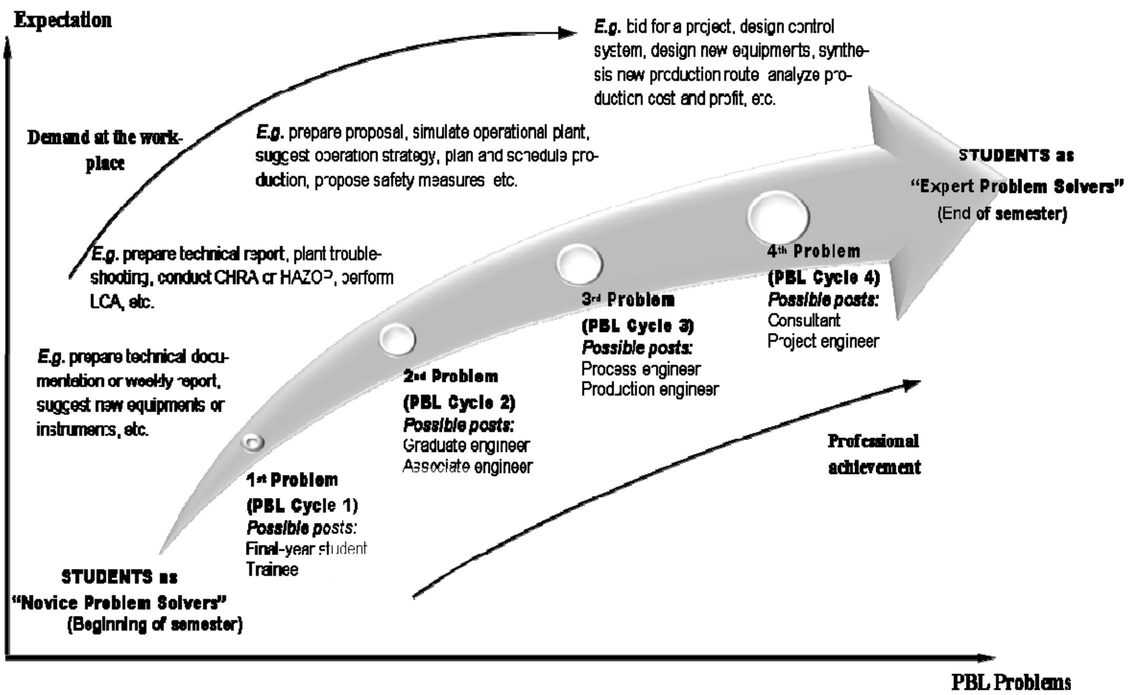

Figure 4.10: Possible posts and job specification as engineers from low level to high level of expectation.

4.3.2 Engineering Problem Solving Elements

How do the students enhance their problem solving elements as they went through CPBL class? This question is investigated from series of students’ reflections and interviews from 2 groups of students, consisting of a total of 7 students. The problem solving process that students went through were problem identification, problem analysis and synthesis and solution generation. Along the process, the students reflected upon their decision and involved seriously in their self-directed learning.

In problem identification, terms such as confuse, learning issues, problem restatement and representation, peer teaching and overall class discussion are frequently used. In analysis and synthesis, terms such as evaluation, handling problems, analysis and synthesis, and understanding are often used. In solution generation, terms that commonly used are overall class discussion, report and presentation, and understanding. These problem solving process in some way or another involved in reflections and self-directed learning, apart from the overall reflection and self-directed learning.

As shown in Table 4.20, upon encountering problems, the students repeatedly mentioned words that can be categorized as problem identification. Among the most popular themes are understandings and learning issues. Another most important theme is team peer teaching. Themes that are significantly important are stage of confusion, overall discussion, reflection, problem representation, and self-directed learning. Other related themes important mention in problem identification that rarely emerged are problem restatement and handling problem. Students were dealing with these at almost every problem they encountered, where learning issues and their understanding towards the problem identification matter the most.

Table 4.21 categorized students' understanding of problem identification. Their utmost concern is the deep understanding of the problems which resulted in the enhancement of their problem identification ability. Surface understanding is also other theme that frequently emerged in the problem identification ability.

Table 4.20: Open coding and repetition for the themes in problem identification

Problem Identification (PI)	**Reflections**				**Interviews**		**∑**
	Problem 1	**Problem 2**	**Problem 3**	**Meta**	**Group 1**	**Group 2**	
Stage of Confusion	5	1	3	1	3	3	16
Problem Restatement	0	1	0	1	2	1	5
Representation	3	2	1	0	3	4	13
Learning Issues	5	2	3	2	3	3	18
Team Peer Teaching	7	4	2	1	1	2	17
Overall Class Discussion	4	3	3	2	0	2	14
Handling Problem	1	2	1	0	0	0	4
Reflection	0	3	2	3	2	3	13
Self-Directed Learning	2	0	3	1	2	0	8
Understanding	5	5	10	1	3	5	29

Table 4.21: Surface and deep understanding during problem identification

Understanding PI	**Reflections**				**Interviews**		**∑**
	Problem 1	**Problem 2**	**Problem 3**	**Meta**	**Group 1**	**Group 2**	
Surface	0	2	5	1	1	2	11
Deep	5	3	5	0	2	3	18

Table 4.22 summarized samples of open coding on how students enhanced their problem identification ability. The coding had been validated by experts in problem solving, CPBL, and qualitative analysis, as discussed in Chapter 3. Emerging themes are considered as saturated if they were frequently mentioned (Corbin and Strauss, 2008). As a rule-of-thumb, themes emerged more than seven times is considered as saturated. The themes are considered triangulated if they emerged from many different sources (Creswell, 2002).

Table 4.22: Samples of open coding for problem identification

Sample Data	Open Coding
The second class discussion was amazing. It was like the explosion of confusion + knowledge + "new" theory + a lot of assumption = more confusion.	Confuse
In our first discussion, the truth is, all of my teammates are blurry including me. We actually don't know how to start this case study. So, all of us together had read again the handout of case study. We wrote it down one by one what we are supposed to do in this case study 3. Finally, we are clearer what we have to do after jotting things down in a piece of paper.	Handling Problem
First of all, I try to understand all the knowledge which is new for me and made it into a mind map. For convenient and simple, it was an easier way to explain to my teammates.	Representation
Our first meeting was on the learning issues that we have discussed in the class. In order to have an effective meeting what we did was to read on all the learning issues and just focus more on one particular topic.	Learning Issues
The second class discussion was amazing. It was like the explosion of confusion + knowledge + "new" theory + a lot of assumption = more confusion	Overall Class Discussion
As for my problem solving skills, there are slight improvements. The time requires getting to the problem statement gets shorter. This indicates that I know what my problem is and where I should head and what I should do	Restatement
The first step to start to solve a problem is usually the most difficult step. CPBL is just like a learning process that helps me to have courage and know how to step out the first step.	Reflection on PI
As for the feedback controller modes, at first, I was totally 'blur' when my teammates explained about the controller modes during peer teaching. They were total new things to me, and they looked very difficult to be understood. However, I decided to spend some time to understand more about the controller modes. Then, after more readings, I found myself having better understanding.	Self-Directed Learning on PI
Discussions in a team really help me a lot where we can teach them and learn with them. It actually gives me a long duration for me to remember what I have learn because before this, after I learned by my own and do not discuss to anyone, by a week, I couldn't remember what I've just learned before.	Team Peer Teaching
I was so happy that I started to love programming part. I even helped other groups that seek for my help to identify their problem.	Understanding on PI

After problem identification, the students repeatedly mentioned words that can be categorized as problem analysis and synthesis. Table 4.23 summarized the open coding of the themes associated to problem analysis and synthesis. Among the most popular themes are understanding and problem analysis. Problem synthesis is another theme that is also repeatedly mentioned. Other related themes that also emerged in this category are evaluation, reflection, self-directed learning and handling problem. Students were dealing with these at almost every problem they encountered, where their understanding towards problem analysis and synthesis matter the most.

Table 4.23: Open coding and repetition of the themes for problem analysis and synthesis

Problem Analysis and Synthesis	**Reflections**				**Interviews**		$\sum$
	Problem 1	**Problem 2**	**Problem 3**	**Meta**	**Group 1**	**Group 2**	
Problem Analysis	3	3	3	2	3	4	18
Problem Synthesis	1	1	2	1	2	0	7
Evaluation	0	0	2	0	1	0	3
Reflection	0	1	1	0	2	1	5
Self-Directed Learning	0	0	2	0	0	1	3
Handling Problem	2	0	2	0	0	0	4
Understanding	4	3	3	0	4	4	18

Table 4.24 categorized the students' understanding of problem analysis and synthesis. Their utmost concern is their deep understanding of the problems which caused the enhancement of their problem analysis and synthesis ability. Table 4.25 summarized samples of open coding on how the students enhancing their problem analysis and synthesis ability.

Table 4.24: Surface and deep understanding during problem analysis and synthesis

Understanding A&S	**Reflections**				**Interviews**		∑
	Problem 1	**Problem 2**	**Problem 3**	**Meta**	**Group 1**	**Group 2**	
Surface	0	0	1	0	1	1	3
Deep	4	3	2	0	3	3	15

Table 4.25: Samples of open coding for problem analysis and synthesis

Sample Data	Open Coding
For the first meeting, I showed my lists to "S1G1" and "S3G1" to ensure our work go smoothly. But, not all what we planned will go as we want. We still stuck with some problems in the progress. As my observation, we took much time just to complete the block diagram. That's why systematic work also needed in technical work.	Evaluation
But if looked back on what they did, I guess that their meeting was ineffective. This makes me to go into the problem and always view the problem at different angle so that our team will not face the similar problem and always ask when there is question.	Handling Problem
We analyze each of the graphs and try to get the data needed.	Analysis
Now I know how to integrate	Synthesis
Before, I just see the problem and solve it. But now I can provide more alternative to it.	Reflection on A&S
Through this case study I think it helps me to develop life-long or independent learning skills as well as to be critical thinker. Not all the information from book and internet is correct. Therefore, I need to know which is correct and applicable.	SDL on A&S
I always explore my thinking out of the boundary	Understanding on A&S

The final process in solving problem is generating solution. Table 4.26 shows open coding for the solution generation process. In the process, the most popular themes are solution understanding, reflection and overall class discussion. Other themes that are also important are report and presentation, and self-directed learning. In generating solution, the students would really like to ensure their deep understanding from the problem that they solved. They use the overall class discussion to share their understanding and giving comments on other groups' solutions.

Table 4.26: Open coding for solution generation

Solution Generation (SG)	Reflections				Interviews		Σ
	Problem 1	Problem 2	Problem 3	Meta	Group 1	Group 2	
Overall class discussion	6	5	3	2	2	1	19
Report and Presentation	0	3	1	0	0	1	5
Reflection	3	4	4	2	2	2	17
Self-directed Learning	0	0	1	0	2	2	5
Understanding	2	5	6	1	4	4	22

Table 4.27 categorized students' concern on their understanding of the solution generation. Their utmost concern is their deep understanding from the generated solution which caused the enhancement of their solution generating ability.

Table 4.27: Surface and deep understanding during solution generation

Understanding SG	Reflections				Interviews		Σ
	Problem 1	Problem 2	Problem 3	Meta	Group 1	Group 2	
Surface	0	2	0	0	1	1	4
Deep	2	3	6	1	3	3	18

Table 4.28 summarized samples of open coding on how the students enhancing their solution generating ability. This open coding had also been validated by experts in problem solving, CPBL and qualitative analysis.

Self-directed learning is another important problem solving element that engineering students need to enhance in order to be good problem solvers. As seen in all open coding of problem solving processes, each element of the process consists of vignettes about self-directed learning. Table 4.29 and Table 4.30 are open coding and sample of open coding for self-directed learning for the overall problem solving process. The theme is very popular and can be observed many times throughout the students' reflection and interviews.

Table 4.28: Samples of open coding for solution generation

Sample Data	Open Coding
I love to have those kind of participation that given by other group because when we discuss we can see many different things and even "new" theories coming out. It is funny but as well effective.	Overall Class Discussion
The tedious part is sometimes, it really hard to reach to one final answer because all have different views on the topic that we discuss. At the end of CS1, I felt that our group can do better than that.	Reflection on SG
After some correction by everyone on the solution, G1S1 started to complete the simulation. Then, me and Lim started to complete the report. Undeniable, I never worked with someone like Lim. I can say that we have good chemistry. I started to do one part and she do another part and it continued until the report slightly finished. Then, we discussed on the response of the model. Everyone gave opinion and suggestion freely and finished within 1 hour. After typing on the discussion and editing, we completed the report successfully at 4a.m.	Report and Presentation
Before attend discussion, I already finish the report based on my understanding. I really think it was a simple task. So, I thought our meeting will finished by 2 hours. On the discussion, I propose my solution.	Self-directed Learning
But the most interesting part is when completing final phase. That is the time where I can connect all the knowledge to one small design. I know where to begin and what to do.	Understanding on SG

Table 4.29: Open coding and repetition of the theme for self-directed learning

Self-Directed Learning	Reflections				Interviews		Σ
	Problem 1	Problem 2	Problem 3	Meta	Group 1	Group 2	
Self-Directed Learning	5	3	4	2	3	3	20

Table 4.30: Samples of open coding for self-directed learning

Sample Data	Open Coding
On my learning process, it proves that I can be independent to get new knowledge. It is only the matters to get the confidence within myself and the place to seek for verification of the idea that passes my mind. For that, what I did in the class was to ask question in the overall class discussion.	Self-directed learning on PSP

Table 4.31 shows summary of open coding for overall reflections on problem solving process. The most popular theme is positive aspect of the reflection. Table 4.32 shows example of vignettes on positive aspect and negative aspects of open coding. The mostly positive aspects of reflections mean that students' positively reflected their thinking process in solving problem, thus enhancing their problem solving skills.

Table 4.31: Open coding and repetition of the themes for reflection

Reflection	Reflections				Interviews		Σ
	Problem 1	Problem 2	Problem 3	Meta	Group 1	Group 2	
Negative Aspects	0	3	4	0	2	3	12
Positive Aspects	5	4	4	2	3	2	20

Table 4.32: Samples of open coding for reflection

Sample Data	Open Coding
At the beginning it is rather difficult because we don't know anything at all.	Negative
Before this I just read and then I don't know where to integrate and then, how to integrate. Now I know how to integrate, rather than just study.	Positive

Table 4.33 shows the problem solving elements' themes emerged from several sources. Due to space limitation, only one reference for each source is highlighted for data triangulation purposes. Some sources might have more than 20 references for one particular theme. All the listed themes are saturated and triangulated, since they emerged several times and from different sources. As seen in the table, all the themes emerged are classified into their related categories.

Table 4.33: Saturated themes and sample sources for data triangulation (problem solving elements)

Categories	Sources
Problem Identification	
Learning Issues	DRP1GISI:21, DRP1G1S2:30, DRP1G1S3:13, DRP1G2S1:4, DRP1G2S4:13, DRP2G1S1:40, DPR2G1S3:5, DRP3G1S1:27, DRP3G1S2:34, DRP3G1S3:42, DRP4G2S3:83, DRP4G2S4:14, IIG1S1:200, IIGIS2:432, IIG1S3:181, IIG2S1:492, IIG2S3:235, IIG2S4:499
Team Peer Teaching	DRP1GISI:24, DRP1G1S2:40, DRP1G1S3:31, DRP2G1S1:72, DRP2G1S2:61, DRP2G1S3:62, DRP2G2S1:36, DRP2G2S2:23, DRP2G2S3:40, DRP2G2S4:17, DRP3G1S3:51, DRP3G2S3:14, DRP3G2S4:16, DRP4G2S4:16, IIG1S1:1137, IIG2S2:154, IIG2S3:636
Stage of Confusion	DRP1G1S2:10, DRP1G1S3:13, DRP1G2S2:4, DRP1G2S3:33, DRP1G2S4:24, DRP2G1S3:27, DRP3G1S1:27, DRP3G2S2:6, DRP3G2S3:12, DRP4G1S3:6, IIG1S1:1155, IIGIS2:818, IIG1S3:243, IIG2S1:511, IIG2S3:338, IIG2S4:215
Overall Class Discussion	DRP1GISI:66, DRP1G1S3:19, DRP1G2S3:58, DRP1G2S4:24, DRP2G1S3:8, DRP2G2S4:19, DRP3G1S2:34, DRP3G1S3:29, DRP3G2S4:11, IIG2S1:684, IIG2S2:766
Reflection	DRP2G1S1:21, DRP2G1S2:9, DRP2G2S3:40, DRP3G1S1:27, DRP3G2S3:9, DRP4G1S1:11, DRP4G1S3:5, DRP4G2S2:30, IIGIS2:237, IIG1S3:181, IIG2S1:684, IIG2S2:689, IIG2S3:136, IIG2S4:215
Representation (KNL)	DRP1G1S3:17, DRP1G2S4:14, DRP2G1S3:7, DRP3G1S3:4, IIG1S1:480, IIGIS2:361, IIG1S3:183, IIG2S1:422, IIG2S3:136, IIG2S4:266
Self-directed Learning	DRP1GISI:66, DRP1G1S3:25, DRP3G1S3:9, DRP3G2S3:15, DRP3G2S4:19, DRP4G2S4:14, IIGIS2:514, IIG1S3:196
Deep Understanding	DRP1GISI:35, DRP1G1S2:28, DRP1G1S3:31, DRP1G2S1:12, DRP1G2S3:35, DRP2G1S1:37, DRP2G1S3:11, DRP2G2S1:9, DRP3G1S2:7, DRP3G1S3:11, DRP3G2S1:34, DRP3G2S3:13, DRP3G2S4:18, IIG1S1:181, IIGIS2:359, IIG2S1:592, IIG2S3:651, IIG2S4:290
Surface Understanding	DRP2G1S1:21, DRP2G2S4:19, DRP3G1S1:27, DRP3G1S3:13, DRP3G2S1:9, DRP3G2S2:6, DRP3G2S3:12, DRP4G1S1:10, IIGIS2:845, IIG2S2:176, IIG2S4:705

Note:
DRP#G#S#:# = Document Reflection for Problem #, Group #, Student #: Line #.
I#G#S#:# = Interview #, Group #, Student #: Line #

Table 4.33: Saturated themes and sample sources for data triangulation (problem solving elements) – continue.

Categories	Sources
Problem Analysis and Synthesis	
Analysis	DRP1G1S3:39, DRP1G2S3:33, DRP2G1S2:12, DRP2G1S3:29, DRP2G2S3:30, DRP3G1S1:35, DRP3G1S3:87, DRP3G2S4:37, DRP4G1S1:62, DRP4G1S3:31, IIG1S1:661, IIGIS2:730, IIG1S3:277, IIG2S1:816, IIG2S2:250, IIG2S3:344, IIG2S4:437
Synthesis	DRP1G2S1:19, DRP2G1S3:36, DRP3G1S1:35, DRP3G2S4:37, DRP4G1S1:62, IIG1S1:796, IIGIS2:818
Deep Understanding	DRP1G1S3:49, DRP1G2S1:19, DRP1G2S3:33, DRP1G2S4:34, DRP2G1S1:64, DRP2G1S3:27, DRP2G2S1:9, DRP3G1S1:49, DRP3G1S3:85, IIG1S1:512, IIGIS2:1979, IIG1S3:340, IIG2S2:248, IIG2S3:513, IIG2S4:436
Solution Generation	
Reflection	DRP1GISI:30, DRP1G1S3:59, DRP1G2S3:32, DRP2G1S2:17, DRP2G1S3:35, DRP2G2S1:29, DRP2G2S3:47, DRP3G1S1:54, DRP3G1S2:28, DRP3G2S3:36, DRP3G2S4:18, DRP4G1S1:13, DRP4G2S3:55, IIG1S1:964, IIG2S1:1187, IIG2S4:500
Overall Class Discussion	DRP1GISI:40, DRP1G1S2:42, DRP1G2S1:41, DRP1G2S2:12, DRP1G2S3:53, DRP1G2S4:28, DRP2G1S2:17, DRP2G2S1:29, DRP2G2S4:23, DRP3G1S2:12, DRP3G2S3:95, DRP4G2S3:53, IIG1S3:1398, IIG2S4:1698
Deep Understanding	DRP1G1S3:58, DRP1G2S3:33, DRP2G1S1:31, DRP2G2S1:30, DRP2G2S3:3, DRP3G1S1:40, DRP3G1S2:16, DRP3G1S3:73, DRP3G2S2:30, DRP3G2S3:34, DRP3G2S4:18, DRP4G1S1:13, IIG1S1:352, IIGIS2:894, IIG2S2:78, IIG2S3:513, IIG2S4:500
Self-Directed Learning for Overall Problem Solving Process	DRP1GISI:66, DRP1G1S3:71, DRP1G2S1:34, DRP1G2S3:46, DRP1G2S4:36, DRP2G1S1:42, DRP2G1S2:9, DRP2G1S3:13, DRP3G1S1:72, DRP3G1S2:7, DRP3G2S2:34, DRP3G2S3:18, DRP4G1S1:46, DRP4G2S1:18, IIG1S1:69, IIGIS2:854, IIG1S3:659, IIG2S1:1381, IIG2S2:761, IIG2S4:1502
Reflection for Overall Problem Solving Process	
Positive	DRP1GISI:4, DRP1G1S2:36, DRP1G1S3:68, DRP1G2S3:5, DRP1G2S4:36, DRP2G1S1:53, DRP2G1S2:7, DRP2G2S1:22, DRP2G2S3:21, DRP3G1S3:56, DRP3G2S1:3, DRP3G2S3:38, DRP3G2S4:4, DRP4G1S1:95, DRP4G2S3:53, IIG1S1:782, IIGIS2:1162, IIG1S3:195, IIG2S4:1389
Negative	DRP2G1S3:65, DRP2G2S1:40, DRP2G2S4:7, DRP3G1S1:3, DRP3G1S2:28, DRP3G2S1:37, DRP3G2S3:93, IIG1S1:614, IIGIS2:490, IIG2S1:2454, IIG2S3:1126, IIG2S4:979

4.3.3 Students' Motivation and Learning Strategies

Since problem solving in engineering is very challenging, the students need to be highly motivated and employ various kinds of learning strategies. The question is how do the students improve the learning motivation and their employment of learning strategies that will eventually enhance their problem solving skills? The question is answered using qualitative analysis. The analysis will also investigate the reason behind the slight reduction of the extrinsic goal orientation as seen in the result of the quantitative analysis.

These questions are also investigated from series of students' reflections and interviews from 2 groups of students. A summary of themes emerged from the investigation and numbers of the themes repeated are shown in Table 4.34. From the analysis, motivation and learning strategies is divided into two elements: motivation strategies and learning strategies.

Table 4.34: Open coding and repetition of the theme for self-directed learning

Learning Motivation and Strategies	**Reflections**				**Interviews**		**Σ**
	Problem 1	**Problem 2**	**Problem 3**	**Meta**	**Group 1**	**Group 2**	
Motivation							
Expectancy	5	3	3	3	1	4	19
Intrinsic	4	2	6	2	2	4	20
Extrinsic	2	3	5	1	2	4	17
Task Value	1	2	4	0	0	2	9
Strategies							
Organization	3	2	2	1	3	2	13
Critical Thinking	4	1	4	1	2	2	14
Effort Regulation	5	5	2	3	3	4	22
Help Seeking	7	4	6	2	2	4	25

In the motivation strategies, themes such as expectation, intrinsic goal orientation, and task value emerged. In the learning strategies, themes such as critical thinking, effort regulation, help seeking, and organization emerged. These themes are perfectly in line with the selected MSLQ constructs used in the instrument for quantitative analysis. All the themes were mentioned several times, with help seeking theme emerging the most, followed by effort regulation. The next theme that was mentioned most is their intrinsic goal orientation. It is interesting to note that the intrinsic goal orientation theme were mentioned more than the extrinsic goal orientation, which signals the reason why there is a slight reduction of the extrinsic goal orientation as seen in the result of the quantitative analysis. Table 4.35 shows samples of data related to the themes. This table, together with Table 4.36 shows how students improve their learning motivation and their employment of learning strategies that will eventually enhancing their problem solving skills.

Table 4.35: Samples of open coding for motivation and learning strategies

Elements	Sample Data	Open Coding
Motivation Strategies	I realized that if all of us contribute our parts during discussions, the outcome will be better as there are more ideas being generated.	Expectancy
	I won't be able to learn a new thing if I easily give up trying and learning from mistakes. We learn from mistakes. If I keep on trying and am persevere, then eventually I will be able to master the things I am learning.	Intrinsic
	As overall, I am very happy to have a great time during this class although sometime have a hard time. Lastly, for sure I need to get A in this subject.	Extrinsic
	As for Simulink, it was totally new to me. It was fun and interesting, seeing how graphs can be produced and learning how to analyze the graphs.	Task Value
Learning Strategies	With more feedbacks and comments, the original solution is improved and made better, and eventually the problem can be solved in a better way.	Critical Thinking
	First we need to study like mad people and then vomit it out to our team mate then only the real thing will come, a clearer picture of the content. It actually happens on all the four phases where we don't know anything but at last produces something.	Effort Regulation
	When we are discussing about certain topics, we help each other to understand the topic better.	Help Seeking
	Looking at the syllabus, I noticed that I can see the connection of all the 3 phases. Problem statement must be clear before confronting the problem.	Organization

Table 4.36 shows the motivation and learning strategies themes emerged from several sources. All the listed themes are saturated and triangulated, since they emerged several times and from different sources. As seen in the table, all the themes emerged are classified into their related categories.

Table 4.36: Emerging themes and sample sources for data triangulation (motivation and learning strategies)

Categories	Sources
Motivation	
Expectation	DRP1GISI:15, DRP1G1S3:63, DRP1G2S1:35, DRP1G2S2:23, DRP1G2S3:46, DRP2G1S1:97, DRP2G1S3:65, DRP2G2S3:36, DRP3G1S2:52, DRP3G2S3:46, DRP3G2S4:18, DRP4G1S2:7, DRP4G2S1:25, DRP4G2S3:82, IIG1S1:633, IIG2S1:2426, IIG2S2: 68, IIG2S3:651, IIG2S4:1281
Intrinsic Goal Orientation	DRP1G1S3:25, DRP1G2S1:36, DRP1G2S2:23, DRP1G2S3:35, DRP2G1S1:6, DRP2G2S3:36, DRP3G1S1:72, DRP3G1S2:8, DRP3G2S1:28, DRP3G2S2:30, DRP3G2S3:40, DRP3G2S4:4, DRP4G2S3:81, DRP4G2S4:17, IIG1S2:894, IIG1S3:896, IIG2S2:740, IIG2S3:989, IIG2S4:2011
Extrinsic Goal Orientation	DRP1GISI:8, DRP2G1S1:94, DRP2G1S2:71, DRP2G2S3:12, DRP3G1S1:68, DRP3G1S2:53, DRP3G2S1:38, DRP3G2S3:51, DRP3G2S4:41, DRP4G1S2:38, IIG1S3:896, IIG2S1:202, IIG2S2:753, IIG2S3:1128, IIG2S4:1566
Task Value	DRP1G1S3:47, DRP2G1S1:6, DRP2G1S3:30, DRP3G1S1:49, DRP3G2S2:27, DRP3G2S3:38, DRP3G2S4:4, IIG2S1:1465, IIG2S3:790
Learning Strategies	
Critical Thinking	DRP1GISI:8, DRP1G1S3:49, DRP1G2S3:30, DRP1G2S4:28, DRP2G1S1:8, DRP3G1S1:68, DRP3G1S2:14, DRP3G2S3:25, DRP3G2S4:25, DRP4G2S3:59, IIG1S1:347, IIG1S2:838, IIG2S1:1399, IIG2S4:1407
Effort Regulation	DRP1GISI:17, DRP1GIS2:20, DRP1G1S3:75, DRP1G2S2:33, DRP1G2S4:41, DRP2G1S1:21, DRP2G1S2:7, DRP2G1S3:65, DRP2G2S3:47, DRP2G2S4:117, DRP3G1S1:8, DRP3G2S3:16, DRP4G1S1:86, DRP4G2S1:25, DRP4G2S3:17, IIG1S1:160, IIG1S2:1430, IIG1S3:416, IIG2S1:1300, IIG2S2:727, IIG2S4:2011
Help Seeking	DRP1GISI:66, DRP1GIS2:33, DRP1G1S3:31, DRP1G2S1:22, DRP1G2S2:23, DRP1G2S3:43, DRP1G2S4:28, DRP2G1S1:37, DRP2G1S3:53, DRP2G2S1:14, DRP2G2S3:78, DRP3G1S1:27, DRP3G1S2:52, DRP3G2S1:15, DRP3G2S2:16, DRP3G2S3:25, DRP3G2S4:28, DRP4G2S1:14, DRP4G2S3:51, IIG1S1:621, IIG1S2:490, IIG2S1:431, IIG2S2:683, IIG2S3:900, IIG2S4:1697
Organization	DRP1GISI:32, DRP1GIS2:36, DRP1G1S3:31, DRP2G1S1:19, DRP2G2S3:21, DRP3G1S2:41, DRP3G2S1:31, DRP4G1S1:15, IIG1S1:1049, IIG1S2:1421, IIG1S3:853, IIG2S1:1295, IIG2S4:1317

4.3.4 Team Working Effectiveness

One of the very important components of CPBL is cooperative learning. The question is how do students improve their effective team working skills which lead to the enhancement of their problem solving skills? This question is also studied from series of students' reflections and interviews. Themes emerged in the analysis are classified into five categories, which are face-to-face interaction, individual accountability, interdependent, interpersonal skills and regular assessment, with respect to Johnson, Johnson and Smith's (2006) cooperative learning principles.

The themes emerged are discussion, learning, commitment, shared value, tolerance, communication, leadership, managing conflict, time management, peer review and reflection. Communication, leadership, and managing conflict are classified as interpersonal skills; commitment, shared value and tolerance as interdependence; discussion as face-to-face interaction; time management and learning as individual accountability; while peer reviews and reflections are as regular assessment.

Table 4.37 shows open coding and numbers of repetition of themes for interpersonal skills. As shown in the table, all the themes related to interpersonal skills are mentioned several times. Managing conflicts are mentioned the most, than followed by communication, and leadership. The students appreciated the way CPBL enhance their interpersonal skills, especially in terms of conflict management and communication skills thus, enhancing their team work problem solving skills which is very important skills as future engineers. Table 4.38 shows an open coding and numbers of repetition of themes for interdependence. As shown in the table, all the themes related to interdependence are mentioned several times. Commitments are mentioned the most, followed by shared values and tolerance. The students appreciated the way CPBL enhance their interdependence skills, especially in increasing team commitments and their shared values, thus, enhancing their team work problem solving skills.

Table 4.37: Open coding and repetition of the themes for interpersonal skills

Interpersonal Skills	Reflections				Interviews		Σ
	Problem 1	Problem 2	Problem 3	Meta	Group 1	Group 2	
Managing Conflicts	2	5	3	3	3	4	20
Communication	3	2	3	6	2	1	17
Leadership	2	1	2	1	1	0	7

Table 4.38: Open coding and repetition of the themes for interdependence

Interdependence	Reflections				Interviews		Σ
	Problem 1	Problem 2	Problem 3	Meta	Group 1	Group 2	
Shared Value	3	2	4	3	2	3	17
Tolerance	1	1	3	3	1	0	9
Commitment	3	5	6	4	1	4	23

Table 4.39 shows open coding and numbers of repetition of theme for face to face interaction. As shown in the table, the theme discussion emerged many times. It shows that students engaged in team discussion, hence enhancing their team work problem solving skills.

Table 4.39: Open coding and repetition of the theme for face to face interaction

Face to Face Interaction	Reflections				Interviews		Σ
	Problem 1	Problem 2	Problem 3	Meta	Group 1	Group 2	
Discussion	7	4	4	3	3	3	24

Table 4.40 shows open coding and numbers of repetition of theme for individual accountability. As shown in the table, the theme learning emerged many times. It shows how CPBL engaged students in learning by solving problems in teams and to be with their time.

Table 4.40: Open coding and repetition of the theme for individual accountability

Individual Accountability	Reflections				Interviews		Σ
	Problem 1	Problem 2	Problem 3	Meta	Group 1	Group 2	
Learning	4	2	4	1	3	4	18
Time Management	2	2	1	1	2	2	10

Table 4.41 shows an open coding and numbers of repetition of themes for regular self-assessment. As shown in the table, the themes reflection and peer review are categorized as regular self-assessment. Reflection emerged the most. Although peer review is important in assessment, it had been mentioned only a few times. Students assessed their work more through reflection. Since engineering problem solving is an iteration process, regular self-assessment is very important. CPBL does enhance students' problem solving skills through regular self-assessment by engaging the students in reflections and peer reviews.

Table 4.41: Open coding and repetition of the themes for regular self-assessment

Regular Self-Assessment	Reflections				Interviews		Σ
	Problem 1	Problem 2	Problem 3	Meta	Group 1	Group 2	
Peer Review	1	1	0	1	0	1	4
Reflection on TW	3	2	4	3	3	1	16

Table 4.42 shows samples of open coding for team working. The themes are classified into five (5) elements. The elements are based upon the CL principles, which are face-to-face interaction, individual accountability, interdependency, interpersonal skills and regular self-assessment. In terms of team effectiveness, as of TWES, interpersonal skill and face-to-face interaction can be categorized as potency, while individual accountability and regular self-assessment can be categorized as goal setting. All these are very important elements in CPBL that will contribute to the enhancement of team based engineering problem solving skills

Table 4.42: Samples of open coding for team working

Elements	Sample Data	Open Coding
Face-to-face Interaction	I assumed that actually I can determine the control configuration of the loop by looking at the P&I Diagram. If it measured the variables before entered the valve, I assumed it was feed-forward and if it measured the variables at the exit of valve, it was feedback. After discussion in our meeting, I was exactly wrong.	Discussion
Individual Accountability	After discussing in team, standard block diagram was used instead of followed the process in diagram. I do my study on block diagram after meeting with teammates again. It make stronger concept to me after revision done	Learning
Interdependent	In my team, everyone cover up every weakness in others to make our team complete.	Commitment
	Overall, I am satisfied with myself and my team performance and I feel that my team is a Cooperative Learning Group. All my team members willingly spend their weekend to finish the report of Case Study 2 and they are full of commitment. We work as a team and I can say that 'if you jump, I jump and we jump together'	Shared Value
	At first, we were just like a traditional group, but doing a little more than a traditional group. But as time goes by, we improved and performed better, and were more like a cooperative team. We shared with each other and worked with each other. From there, we learnt from each other. Though we are all of different backgrounds, we still worked together very well. I hope this can be a preparation of what I am going to face when I am working.	Tolerance
Interpersonal Skills	I managed to pick up the skill to make others to talk or to initiate a conversation.	Communication
	Perhaps I would love to master the art of "saying the not so good things in a good way"	Leadership
	In CS3, I tried my best to win my teammates' heart back. What I had tried was not just for them, it also for myself. I tried what I could do for the CS3. I had participate all the meetings and learned deeper of the tuning. Yeah! I could help my team to solve some of the problems. I think I had improve my attitude if compare with CS2.	Managing Conflicts
	Then, our first case study came out. I cannot managed my time because of too many things to do. To prevent the time management problem, I included our discussion in the time table. I fixed the time. So that, I will prepared well before attend the meeting and class	Time Management
Regular Assessment	Peer rating and group evaluation will be my milestone to be a good team member and improved my skills in problem solving and being a cooperative group	Peer Review
	We started our serious discussion about shower control system. I gave my opinion but I'm still afraid to deny their opinion although I didn't agree with their opinion. That was my weakness. I still thought they are better than me. Then, they always right. Totally, I am wrong.	Reflection

Table 4.43 shows team effectiveness themes emerged from several sources. All the listed themes are saturated and triangulated, since they emerged several times and from different sources. As seen in the table, all the themes emerged are classified into their related categories.

Table 4.43: Sample of themes and related sources for data triangulation (team effectiveness)

Categories	Sources
Interpersonal Skills	
Managing Conflicts	DRP1GISI:79, DRP1G2S3:46, DRP2G1S1:54, DRP2G1S2:17, DRP2G1S3:98, DRP2G2S3:95, DRP2G2S4:91, DRP3G1S1:68, DRP3G2S2:28, DRP3G2S3:83, DRP4G1S3:20, DRP4G2S1:35, DRP4G2S2:9, IIG1S1: 604, IIG1S2:838, IIG1S3:540, IIG2S1: 1964, IIG2S2:594, IIG2S3:833, IIG2S4:1038
Communication	DRP1GISI:26, DRP1G1S3:63, DRP1G2S1:36, DRP2G1S1:55, DRP2G2S3:78, DRP3G1S1:64, DRP3G2S2:34, DRP3G2S3:86, DRP4G1S1:91, DRP4G1S2:44, DRP4G1S3:24, DRP4G2S1:21, DRP4G2S3:65, DRP4G2S4:20, IIG1S1: 621, IIG1S2:1444, IIG2S3:724
Leadership	DRP1GISI:73, DRP1G1S3:66, DRP2G1S1:38, DRP3G1S1:65, DRP3G1S2:28, DRP4G1S1:91, IIG1S1: 1137
Interdependence	
Commitment	DRP1GISI:19, DRP1G1S3:31, DRP1G2S4:15, DRP2G1S1:71, DRP2G1S2:17, DRP2G1S3:65, DRP2G2S1:29, DRP2G2S3:82, DRP3G1S1:58, DRP3G1S2:34, DRP3G1S3:98, DRP3G2S1:15, DRP3G2S2:26, DRP3G2S3:74, DRP4G1S2:22, DRP4G2S3:51, DRP4G2S4:17, IIG1S2:1125, IIG2S1: 449, IIG2S2:605, IIG2S3:760, IIG2S4:683
Shared values	DRP1GISI:79, DRP1G1S3:47, DRP1G2S3:67, DRP2G2S1:37, DRP2G2S3:93, DRP3G1S3:59, DRP3G2S2:5, DRP3G2S3:71, DRP3G2S4:31, DRP4G1S2:34, DRP4G2S3:51, DRP4G2S4:35, IIG1S1: 619, IIG1S3:715, IIG2S2:248, IIG2S4:881
Tolerance	DRP1GISI:72, DRP2G2S3:92 DRP3G2S2:28, DRP3G2S3:74, DRP3G2S4:21, DRP4G1S1:87, DRP4G1S3:74, DRP4G2S4:32, IIG1S1: 621
Face-to-face interaction	
Discussion	DRP1GISI:30, DRP1GIS2:21, DRP1G1S3:23, DRP1G2S1:22, DRP1G2S2:34, DRP1G2S3:44, DRP1G2S4:30, DRP2G1S1:38, DRP2G1S3:53, DRP2G2S3:78, DRP2G2S4:118, DRP3G1S1:68, DRP3G1S3:98, DRP3G2S1:15, DRP3G2S4:31, DRP4G1S3:10, DRP4G2S3:51, DRP4G2S4:17, IIG1S1:363, IIG1S2:839, IIG1S3:416, IIG2S1:458, IIG2S2:248, IIG2S4:683

Table 4.43: Sample of themes and related sources for data triangulation (team effectiveness) – continue

Categories	Sources
Individual Accountability	
Learning	DRP1GISI:75, DRP1G2S1:22, DRP1G2S2:5, DRP1G2S3:58, DRP2G2S1:14, DRP2G2S3:342, DRP3G1S3:15, DRP3G2S2:23, DRP3G2S4:21, DRP4G2S1:22, IIG1S1:218, IIG1S2:319, IIG1S3:748, IIG2S1:819, IIG2S2:182, IIG2S3:35, IIG2S4:1281
Time management	DRP1GIS2:22, DRP1G2S2:33, DRP2G1S1:83, DRP2G2S1:40, DRP3G2S2:22, DRP4G1S2:7, IIG1S2:1342, IIG2S1:1295, IIG2S3:1148
Regular self-assessment	
Reflection	DRP1GISI:21, DRP1G1S3:4, DRP1G2S3:40, DRP2G2S1:22, DRP2G2S3:88, DRP3G1S2:28, DRP3G2S2:4, DRP3G2S3:66, DRP3G2S4:25, DRP4G1S2:17, DRP4G2S3:64, DRP4G2S4:14, IIG1S1:841, IIG1S2:2350, IIG1S3:87, IIG2S4:1419

4.3.5 The Engineering Problem Solving Assets

How do students acquire this problem solving assets? This question is studied based upon series of students' reflection and interviews. Open coding and repetition of themes emerged from the study are as shown in Table 4.44, Table 4.45 and Table 4.46. Based on the analysis, students' problem solving assets are classified into three elements, which are knowledge, confidence and process. This is in line with Adams (2006) as discussed above.

Themes emerged in the knowledge element are concept, facts, procedural, retention, strategy and understanding. The confidence element consists of belief, motivation and expectation. While analyzing, discussing, executing, questioning, explaining, planning, researching and representing are classified as cognitive processes.

Table 4.44: Open coding and repetition of the themes for knowledge

Knowledge	Reflections				Interviews		∑
	Problem 1	**Problem 2**	**Problem 3**	**Meta**	**Group 1**	**Group 2**	
Retention	1	0	0	0	0	2	3
Facts	0	1	1	0	1	1	4
Strategic	2	3	3	0	2	2	12
Procedural	0	3	1	1	3	2	10
Concepts	1	0	1	0	2	0	4
Understanding	5	3	3	0	3	2	16

Table 4.45: Open coding and repetition of the themes for confidence

Confidence	Reflections				Interviews		∑
	Problem 1	**Problem 2**	**Problem 3**	**Meta**	**Group 1**	**Group 2**	
Expectation	3	4	4	1	1	4	17
Belief	2	2	4	0	3	3	14
Motivation	5	3	4	3	3	2	20

Table 4.46: Open coding and repetition of the themes for cognitive process

Process	Reflections				Interviews		∑
	Problem 1	**Problem 2**	**Problem 3**	**Meta**	**Group 1**	**Group 2**	
Questioning	1	1	1	1	1	0	5
Discussing	5	3	4	1	1	2	16
Explaining	2	1	1	0	0	0	4
Planning	2	4	2	1	3	2	14
Analyzing	1	1	0	0	3	1	6
Executing	3	1	1	1	2	2	10
Researching	7	4	6	0	2	4	23
Representing	0	1	0	0	0	0	1

A good problem solver needs to have adequate knowledge. As shown in Table 4.44, the popular themes emerged as knowledge element in the study are understandings, strategies and procedurals. Facts, concepts and retentions are other important themes in knowledge element, but were rarely mentioned by the students.

In order for the students to be good problem solvers, they must have confidence in solving whatever problems given to them. As illustrated in Table 4.45, motivations, expectations and beliefs are themes emerging in the confidence element. All the themes in the element are popular, however motivations are mentioned the most. To be a good problem solver, student needs to be highly motivated. With higher expectation and self-belief, students will be more motivated. Thus, increase their confidence level to solve any kind of engineering problems.

With knowledge, comes confidence. However, only with knowledge and confidence are not enough to be a good problem solver. Another vital asset is the exercise of cognitive processes. Table 4.46 shows themes emerged in element of cognitive process for the study. The most popular theme emerged in cognitive process is researching, followed by discussing. Other popular themes are planning and executing. In term of popularity, these themes emerged sequentially, starting from students conducting their research of the problem understudied, than discussing and sharing ideas with their teammates, followed by planning, and finally execution. Other themes that also emerged in the element of cognitive process are analyzing, questioning and explaining. Presenting also emerged in the study, but it was mentioned only once.

Table 4.47 shows samples of open coding data related to the emerging of problem solving asset themes, which are classified as knowledge, confidence and cognitive process. Students are considered as good problem solvers, if they can acquire these problem solving assets.

Table 4.48 shows problem solving assets themes emerged from several sources. All the listed themes are saturated and triangulated, since they emerged several times and from different sources. As seen in the table, all the themes emerged are classified into their related categories.

Table 4.47: Samples of open coding for problem solving assets

Elements	Sample Data	Open Coding
Knowledge	Just imagine how it would be if we were just given normal lectures as I would have preferred. All these interesting 'conflicts' would not have happened. But, would I learn anything from the lectures?? Well, most probably the answer would be a "no". Perhaps, I would know the definitions of the terms very well, and be able to differentiate between 'controlled variables' and 'manipulated variables'. But when given the case study, I would certainly got stuck and had difficulties solving them	Concept
	Well, first time is always the most difficult. The more we practice, easier it gets.	Facts
	During class, new method of learning is used. At first, it was difficult. Well, I'm not usually prepared before going to any class. But this class required us to learn ourselves. I'm not that good learning individually. But the approach was different. Learning issues are divided among team members, than we have to teach one another. I start taking it seriously because if our teammate fails to understand the topic, it means I fail. We have the responsibility to make sure our teammate understand it properly.	Procedural
	Discussions in a team really help me a lot where we can teach them and learn with them. It actually gives me a long duration for me to remember what have I learn because before this, after I learn by my own and do not discuss to anyone, by a week, I couldn't remember what I've just learn before.	Retention
	When my teammates voice out their views, I will listen and try to think of some solutions or better ideas that might be helpful.	Strategy
	I would read on my own and then discuss among team mates to see that there is any misunderstanding and verification. If the verification can't be obtained than we will try to get it from the overall discussion	Understanding
Confidence	At the end of case study 1, I felt that our group can do better than that.	Belief
	I might say that I am scare or busy but somehow I still produce what other produce and I hope that I produce a better result than others	Expectation
	At the beginning of the semester, I was quite a passive person during discussions. Luckily, I have supportive teammates who always encouraged me and tend to ask me questions so that I would speak more. Then, I started to be more active to voice out my opinions.	Motivation

Table 4.47: Samples of open coding for problem solving assets – continue

Elements	Sample Data	Open Coding
Process	It makes me realize that study does not mean only reading but also finding ways to apply.	Analyzing
	Talking about the content, we have covered the topic of control configurations and variables in a different way. I would read on my own and then discuss among team mates to see that there is any misunderstanding and verification. If the verification can’t be obtained than we will try to get it from the overall discussion.	Discussing
	What can I say about CS2… undoubtedly, it has taught me a lot of things. First of all, of course, the technical part. I’ve learnt some new things which I have never come across before. The first thing should be deriving the models. Then, it should be learning how to make assumptions. Before, this, I used to make assumptions just as I like, without thinking of the reasons I’m making the assumptions and the consequences of the assumptions. But now, I learnt that for every assumption that I make, I need to justify it and therefore, I can’t just simply assume something. If I can’t justify it, then the assumptions cannot be used since it might affect the models that I derive	Executing
	When we are discussing about certain topics, we help each other to understand the topic better.	Explaining
	In order to perform better, better planning should be carried out. This is to ensure better efficiency in completing the task or assignment. Without planning, more time needed to complete the task because we don’t know the how much time we need for each section and how long it should be done	Planning
	Asking for verification sometimes need a lot of reading and if I don't read a lot then I don't know where to ask and what to ask	Questioning
	Before team meeting, I goggling the related learning issues around internet and reference books.	Researching
	As we know, in designing a model, we cannot have too complicated model and too simplified model	Representing

Table 4.48: Sample of themes and related sources for data triangulation (problem solving assets)

Categories	Sources
Knowledge	
Understanding	DRP1GISI:66, DRP1G1S3:31, DRP1G2S1:34, DRP1G2S2:23, DRP1G2S3:43, DRP2G1S1:93, DRP2G1S3:65, DRP2G2S1:22, DRP3G1S1:14, DRP3G2S1:24, DRP3G2S3:12, IIG1S1:498, IIG1S2:1975, IIG1S3:853, IIG2S1:2426, IIG2S4:1671
Strategies	DRP1G2S2:23, DRP1G2S3:269, DRP2G1S1:97, DRP2G1S3:36, DRP2G2S3:80, DRP3G1S2:41, DRP3G2S1:3, DRP3G2S3:46, IIG1S1:279, IIG1S2:855, IIG2S2:248, IIG2S4:1407
Procedurals	DRP2G1S1:6, DRP2G1S3:29, DRP2G2S3:3, DRP3G2S1:31, DRP4G2S4:14, IIG1S1:621, IIG1S2:1503, IIG1S3:853, IIG2S1:1004, IIG2S4:1671
Confidence	
Motivation	DRP1GISI:79, DRP1GIS2:15, DRP1G1S3:8, DRP1G2S3:58, DRP1G2S4:36, DRP2G1S2:9, DRP2G1S3:65, DRP2G2S3:36, DRP3G1S1:68, DRP3G1S2:7, DRP3G2S1:3, DRP3G2S4:18, DRP4G1S1:77, DRP4G2S3:51, DRP4G2S4:14, IIG1S1:660, IIG1S2:1421, IIG1S3:670, IIG2S1:1220, IIG2S4:2011
Expectation	DRP1GISI:9, DRP1GIS2:19, DRP1G2S4:40, DRP2G1S1:50, DRP2G1S2:7, DRP2G2S3:51, DRP2G2S4:118, DRP3G1S1:54, DRP3G2S1:24, DRP3G2S3:46, DRP3G2S4:18, DRP4G2S4:65, IIG1S1:1426, IIG2S1:1243, IIG2S2:68, IIG2S3:1126, IIG2S4:1879
Belief	DRP1GISI:9, DRP1GIS2:21, DRP2G1S1:6, DRP2G2S3:30, DRP3G1S2:14, DRP3G2S1:3, DRP3G2S3:110, DRP3G2S4:18, IIG1S1:660, IIG1S2:855, IIG1S3:658, IIG2S2:346, IIG2S3:748, IIG2S4:1501
Cognitive Process	
Researching	DRP1GISI:66, DRP1G1S3:71, DRP1G2S2:22, DRP2G1S1:86, DRP2G1S3:12, DRP3G1S1:76, DRP3G1S2:7, DRP3G2S1:34, DRP3G2S2:35, DRP3G2S3:18, IIG1S1:841, IIG1S2:864, IIG2S1:2956, IIG2S2:751, IIG2S3:629, IIG2S4:1502
Discussing	DRP1GISI:30, DRP1G1S3:63, DRP1G2S1:36, DRP1G2S2:23, DRP1G2S3:53, DRP2G1S3:65, DRP2G2S1:22, DRP2G2S3:78, DRP3G1S1:64, DRP3G2S1:28, DRP3G2S2:34, DRP4G2S1:23, IIG1S1:1155, IIG2S2:248, IIG2S3:651
Planning	DRP1GISI:6222, DRP1GIS2:25, DRP2G1S1:83, DRP2G2S1:40, DRP2G2S3:47, DRP2G2S4:58, DRP3G1S2:44, DRP3G2S3:46, DRP4G1S2:7, IIG1S1:363, IIG1S2:1947, IIG1S3:206, IIG2S1:421, IIG2S4:1671
Executing	DRP1GISI:17, DRP1G1S3:63, DRP1G2S3:46, DRP2G2S3:3, DRP3G2S4:28, DRP4G2S1:17, IIG1S1:279, IIG1S3:206, IIG2S1:1004, IIG2S2:1671, IIG2S4:1671

4.4 Assessments

Assessment breakdown for the course can be seen in Table 4.49 (Mohd-Yusof, et. al., 2011). The assessment of problems was mostly individual, except for the report, which is a team effort. Marks received by each student from the report are multiplied by an autorating factor (Kaufman and Felder, 2000) calculated based upon peer rating for the individual students at the end of each problem. 5-point rubrics designed according to the SOLO taxonomy (Biggs, 1996) were used to grade problem restatements and identification, peer teaching notes and reports.

Table 4.49: Course assessment division

Course Assessment	**Marks**
Two written tests	15 %
Three problems • Problem restatement & identification • Peer teaching notes • Report • Written reflection	25%
Final examination • Final problem (10%) • Final written examination (40%)	50%
Others • Tutorials and quizzes • e-learning and class participation	10%
Total	100%

Apart from the problems, there are two written tests and final examination. The final examination consists of a final problem and a written examination. During the final problem, students did not receive much guidance or facilitation. Questions given in the written examinations matched the cognitive taxonomy level of the outcomes as well as the teaching and learning activities that students had undergone in the course.

Results of the two tests and the final examination were analyzed to gauge the enhancement of students' deep understanding of the course. The tests and final examination papers were analyzed to select problems that required deep understanding to solve. Only questions with higher level of taxonomy are considered for the analysis. It is expected that upon solving a series of case studies, the students will directly improve their deep understanding, which should be reflected in their tests and final examination.

Table 4.50 shows the total percentage scores of the higher level taxonomy questions for the tests and the final examination of all seven students involved in the research. The corresponding scores are illustrated in Figure 4.11. As seen in the graph, all students that scored lower in their deep understanding marks during test 1 had improved their scores in test 2 and in the final examination. However, student SIG1, who scored the highest in test 1 and test 2 did not do as well in his final examination. The rest of the students almost maintained their high scores in all their tests and final examination. In terms of enhancement, student S3G1 improved the most. It is important to mention here that final examination questions was the most challenging, followed by test 2 and then test 1.

Table 4.50: Percentage scores of deep understanding problems

Students \ Exams	Test 1	Test 2	Final
S1G1	82	84	61
S2G1	66	58	71
S3G1	8	58	61
S1G2	40	62	66
S2G2	42	64	72
S3G2	52	68	57
S4G2	72	68	64

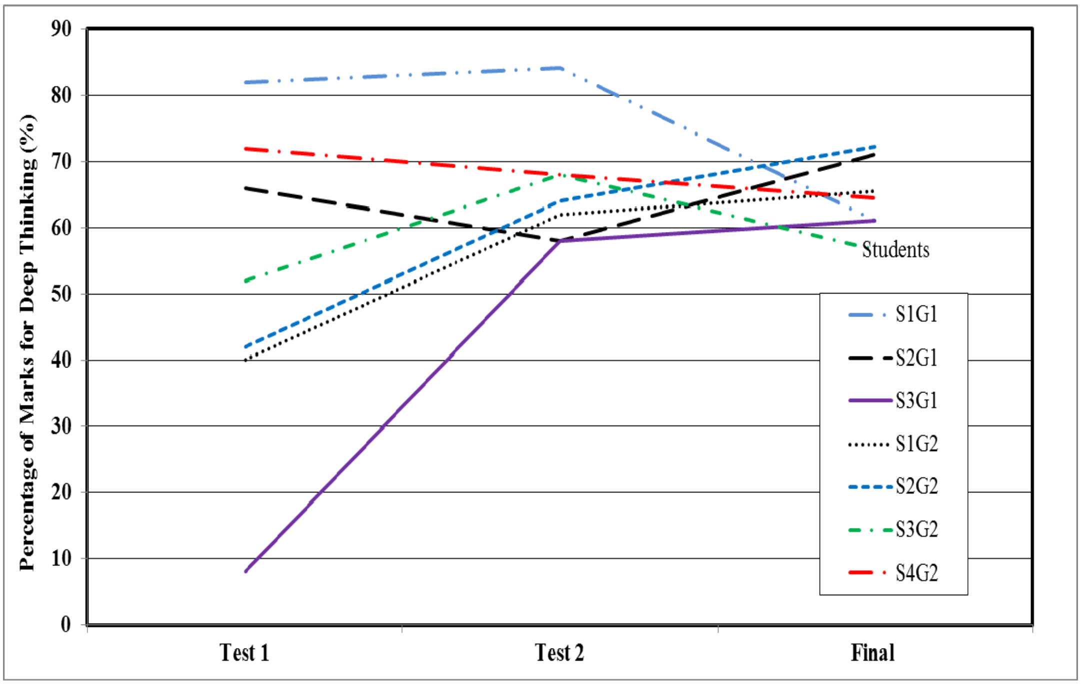

Figure 4.11: Enhancement of percentage score of deep understanding problems.

4.4.1 Students' Perceptions

At the end of the semester students were asked to evaluate their perceptions on their ability in solving complex workplace problems. Before the students rate themselves, the researcher ensured that all of them understood what it meant by complex workplace problems. The ratings are based on the students' perception towards themselves in solving workplace problem at the end of every case study. Table 4.51 and Figure 4.12 show the result of the study. As seen from the graph, all the students believed they progressively improved their skills in solving workplace problems. When asked about their readiness to start a career as engineers upon completing the course, all of them agreed they are almost ready to take the challenge, thus are considered themselves as expects in their field, as commented by these students:

"Finally I can shout I have done CONTROL CLASS!!!!. It was actually a pretty well-defined class where it really guided me to become an engineer"

G1S1

"From this, I could see that different people have different views since we always look at things from different viewpoints. Just imagine how it would be if we were just given normal lectures as I would have preferred. All these interesting "conflicts" would not have happened. But, would I learn anything from the lectures?? Well, most probably the answer would be a "no". Perhaps, I would know the definitions of the terms very well, and be able to differentiate between 'controlled variables' and 'manipulated variables'. But when given the case study, I would certainly get stuck and had difficulties solving them. However, now, with peer teaching and class discussions, I can discuss with others, and we share whatever we know with each other. From there, we get different views and ideas of solving the problems. Then, we will learn more, compared to just studying on our own. Now, not only do we understand the topics that were being discussed, we can even master the topics better"

G2S2

Table 4.51: Students' perceptions on their ability to solve workplace problems

Problems / Students	Case Study 1	Case Study 2	Case Study 3	Case Study 4
S1G1	2	4	6	7
S2G1	6	6.5	8	9
S3G1	4	5	6	8
S1G2	3	5	7	9
S2G2	5	5.5	6	7
S3G2	3	4	5	7
S4G2	2	3	6	7

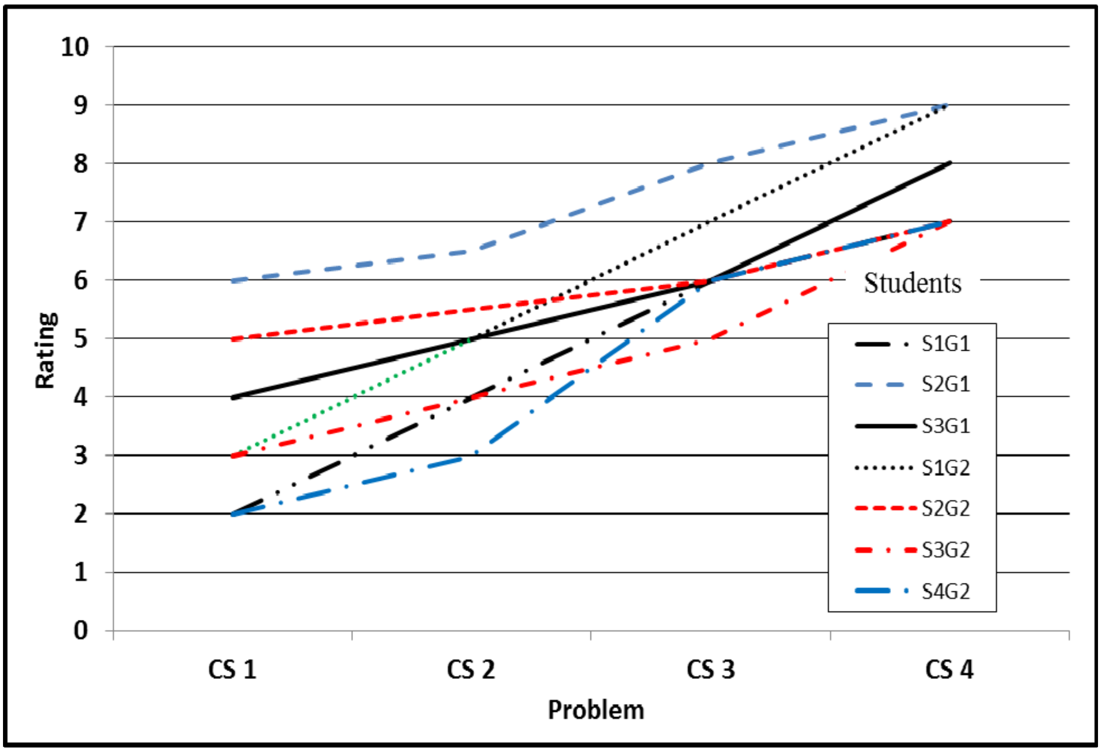

Figure 4.12: Problem solving skills enhancement as perceived by the students

4.5 Conclusion

The quantitative and qualitative methods in this chapter had provided numerous data in the analyses to find answer to the research questions. The quantitative analysis used the EPSI, MSLQ and TWES instruments to find answer to the first research question. While for the second question, the grounded theory approach had been used for the qualitative analysis, started with the description of CPBL approach, and ended with the assessments of deep thinking. Several emerging themes had been categories in the analyses. In the next chapter all these quantitative and qualitative data are synthesized to attain the results.

CHAPTER 5

RESULTS, CONCLUSION AND RECOMMENDATION

5.1 Introduction

Cooperative Problem-Based Learning (CPBL) methodology is a hybrid model of Cooperative Learning (CL) and Problem-Based Learning (PBL) (Mohd-Yusof and Helmi, 2010). CL is a systematic team working approach in learning where all CL principles are applied (Johnson, Johnson and Smith, 2002, and Smith and Imbrie, 2004). PBL is a student-centered, inductive-based learning methodology, where using self-directed learning to solve ill-structure problems are the core principles (Barrows and Tamblyn, 1980; Hmelo-Silver, 2004; and Prince and Felder, 2006). Because of the challenges of CL and PBL in solving ill-structured problems, students can be easily de-motivated and give up, if not properly facilitated (Mohd-Yusof and Helmi. 2009). In order to enhance engineering students' problem solving skills through CPBL, four important factors are considered. They are the problem solving elements, the students' motivation and learning strategies, the students' team working skills and the students' problem solving assets. In Chapter 4, quantitative and qualitative data gathering and analyses are presented. Based on these data and the analyses, this chapter presents the results according to the four important factors. There are two questions that the researcher investigates;

i. To what extent CPBL approach enhance engineering problem solving skills of engineering students?
ii. How does CPBL improve engineering problem solving skills of engineering students?

The answers to these questions are intertwined with each other. Only if answer for question one gave a positive remark, then the answer for question two is significant. Or else, research question two will explore the opposite. Question one is studied using quantitative analysis while question two is studied using qualitative analysis. Several sub-questions are used in the analysis to ease the investigations. Based upon the results, several sub models of the process of enhancement are proposed. A model of engineering problem solving skills enhancement is proposed by combining all the sub models. Following this, the chapter presents the significance of the study and its limitations. It concludes by putting up several recommendations for future direction including establishing a promising practice to enhance engineering students' problem solving skills through CPBL that needs further investigation.

5.2 Research Question 1: To what extent CPBL model enhance problem solving skills among engineering students?

In this study, the enhancements of engineering problem solving skills through CPBL are categorized based upon four factors.

Factor 1: The Students' Problem Solving Elements
Factor 2: The Students' Motivation and Learning Strategies
Factor 3: The Students' Team Working Skills
Factor 4: The Students' Problem Solving Assets

Upon learning using CPBL, enhancement of engineering problem solving skills can only be ensured if all these factors are significantly improved. The overall quantitative results of the study are summarized in Figure 5.1 and Table 5.1.

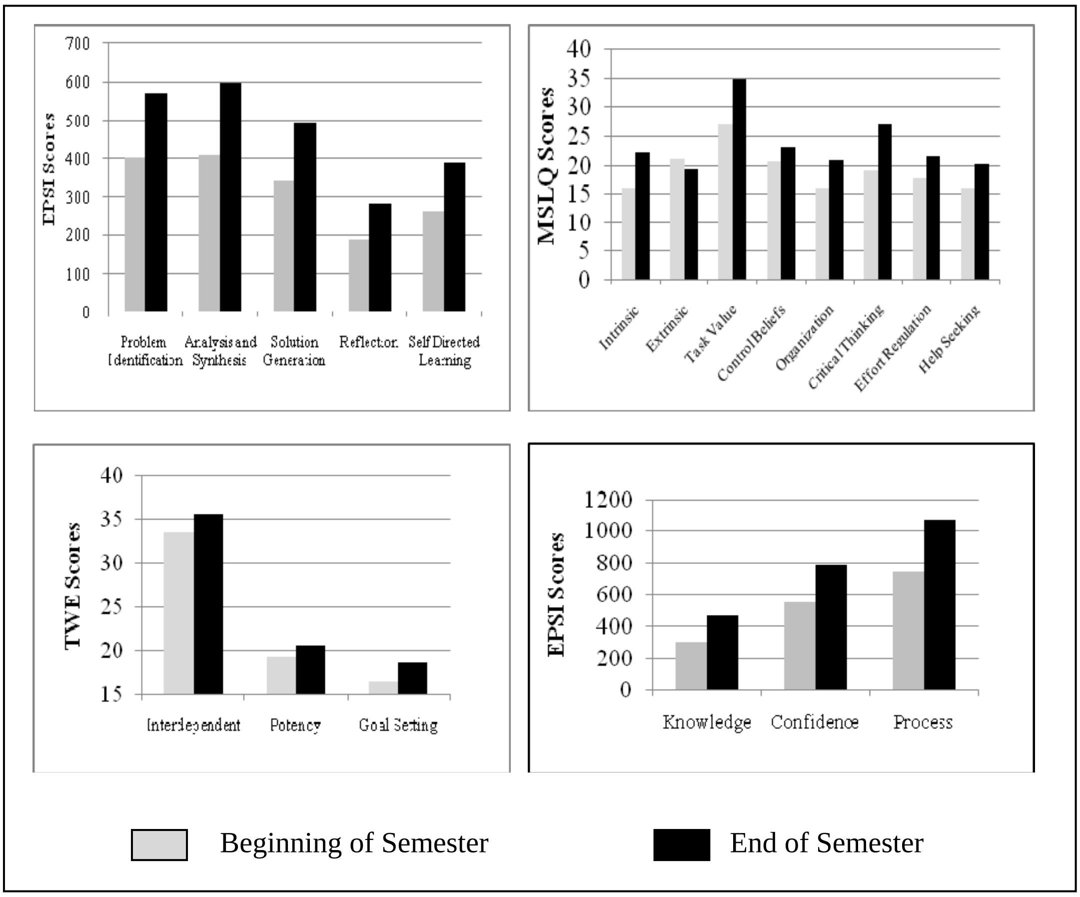

Figure 5.1: Summary results of scores on problem solving skills enhancements

5.2.1 Factor 1: Students' Problem Solving Elements

In CPBL, problem solving elements consist of the problem solving process, students' reflection and students' self-directed learning. Generally, problem solving process involves problem identification, problem analysis and synthesis, and solution generation.

- In problem identification, students gained an understanding of the problem's domain and identified the root causes of the symptoms that they observed.
- In problem analysis and synthesis, students dissected and thoroughly studied the problem with the objective to understand 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.

- In generating solution, students make judgments based on internal criteria that are logically correct and free from errors.
- In students' reflection, students communicate their thoughts by describing what they have learned, how they could make it better, and how it might impact their future.
- Self-directed learning students take control of their learning activities, depending solely on themselves.

Table 5.1: Summary of quantitative result of problem solving skills

Problem Solving Skills	Sig. (2-tailed)	p < .05	Effect Size	Type of Test
Problem Solving Elements				Paired t-test
Problem Identification	0.000	Sig	1.80	
Analysis and Synthesis	0.000	Sig	2.09	
Solution Generation	0.000	Sig	1.84	
Reflection	0.000	Sig	1.59	
Self-directed Learning	0.000	Sig	1.74	
Motivation and Learning Strategies				Paired t-test
Intrinsic	0.000	Sig	1.49	
Extrinsic	0.018	Sig	0.41	
Task Value	0.000	Sig	1.41	
Control Belief	0.000	Sig	0.99	
Organization	0.000	Sig	1.38	
Critical Thinking	0.000	Sig	1.95	
Effort Regulation	0.000	Sig	0.89	
Help Seeking	0.000	Sig	1.30	
Team Working Effectiveness				Wilcoxon Signed Ranks Test
Interdependent	.040	Sig	-0.265	
Potency	.023	Sig	-0.293	
Goal Seeking	.018	Sig	-0.306	
Problem Solving Assets				Paired t-test
Knowledge	.000	Sig	1.92	
Confidence	.000	Sig	1.76	
Process	.000	Sig	2.08	

For the students' problem solving elements, the first research question is quantitatively studied by examining three sub-questions. The sub-questions are:

i. Do students become better problem-solvers in terms of its process?
ii. Do students improve their ability to identify deficiencies in learning and problem solving that they need through reflecting the process that they went through?
iii. Do students become better self-directed learners?

Figure 5.1 and Table 5.1 summarized the quantitative results of the questions. As shown in the figure, at the end of the semester, the Engineering Problem Solving Instrument (EPSI) scores for all elements contributed to the enhancement of engineering students' problem solving skills have increased. As statistically illustrated from the results of paired t-test given in Table 5.1, all EPSI scores in problem solving elements increased significantly. The EPSI scores show the degree of enhancement of the students' deep thinking. Therefore, in terms of enhancement of deep thinking, the students' problem solving process, reflection and self-directed learning improved significantly upon attending a course that used CPBL.

As shown in the table, the effect size of all the elements are greater than 0.8, which indicates that the CPBL teaching methodology had great effect upon the students' deep thinking of all the problem solving elements. The students' deep thinking in problem solving process, reflection and self-directed learning have improved significantly. This means that the CPBL approach in learning does have significant impact on students' problem solving skills. The students had improved their understanding on problems' domain, how the problems emerged and how it grew proportionally. They had improved their problem solving process by knowing how to combine information and understanding in order to make better judgments in generating solutions. The students have improved their thinking skills by learning how to reflect and made better judgments in the future, thus becomes better problem solvers. The students also improved their self directed learning by assuming major responsibilities for the acquisition of knowledge and information.

The result of this study statistically proved that, after going through CPBL process for one semester,

i. students do become better problem-solvers in terms of its process,
ii. 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
iii. students do become better self-directed learners.

This result is in line with Albanese and Mitchell (1993) on how their students perceived PBL. According to Albanese and Mitchell (1993), their students viewed PBL as better prepared themselves in self-directed learning, problem solving, information gathering, and self-evaluation techniques.

5.2.2 Factor 2: The Students' Motivation and Learning Strategies

Selected constructs of the Motivated Strategies for Learning Questionnaire (MSLQ) are used to study the students' motivational and learning strategies upon attending this CPBL course. The motivation section is divided into two components: value and expectancy.

- The value component measures students' goal orientations and their beliefs on the value of a course through three scales consisting of intrinsic goal orientation, extrinsic goal orientation and task value.
- The expectancy component consists of control of learning beliefs that measures the students' expectancy for success in this course.

The learning strategies section is also divided into two components: cognitive/meta-cognitive strategies and resource management strategies.

- Cognitive/meta-cognitive strategies measure students' use of these strategies by using organization and critical thinking.
- Resource management strategies measures students' ability to utilize resources for learning through effort regulation and help seeking.

The first research question is quantitatively studied by examining another sub-question which is the fourth research sub-question. The sub-question is:

(iv). Do students improve their learning motivation and their employment of learning strategies that will enhance their problem solving skills?

Figure 5.1 also shows the MSLQ scores for the beginning and the end of the semester for the course. Referring to Table 5.1, based on paired t-test, the means for all constructs for the end of the semester were found to have significant differences from those for the beginning of the semester. As indicated the table, the effect sizes (d) for all the comparison are also greater than 0.8. However, the effect size of extrinsic goal orientation is smaller than 0.5. An effect size that is greater than 0.8 has great impact in the study, but an effect size that is lower than 0.5 has small impact. This means that the CPBL approach in learning does have greater impact on the students learning motivation and strategies. However the CPBL approach slightly reduced the extrinsic goal orientation of students.

Referring to Figure 5.1 and Table 5.1, the first four constructs in the MSLQ are the scores for the motivation section: intrinsic goal orientation, extrinsic goal orientation, task value and control of learning beliefs. It is interesting to note that all the motivation scores increased significantly, except for extrinsic motivation, which decreased slightly. Although the difference between the end and the beginning of the semester for extrinsic motivation is smaller compared to the other three ($p = 0.000$), it is still significant ($p = 0.018 < 0.05$), though with a smaller impact compared to the rest of the scores. Based on the results, the students' intrinsic motivation, which is based on the desire for mastery and the satisfaction of learning, increased but surprisingly, there was a decrease in extrinsic motivation, which is based on external rewards, such as grades and competition. This result is in line with Deci and Ryan (1991) self-determination theory. It argues that extrinsic motivation can facilitate intrinsic motivation in opposite direction. However, the smaller change in extrinsic motivation compared to the larger change in intrinsic motivation indicates that students have developed the driving force for learning that comes from within, while the smaller decrease in external motivation indicates that though external rewards were still important, they were not as essential as in the beginning of the semester.

The task value had the highest increase which demonstrates that students appreciate the learning process that they went through. The result of the expectancy component, which is measured using the control of learning beliefs, indicated that students had a higher level of confidence in their ability to successfully complete the task, despite the challenging nature of CPBL, at the end of the semester.

Referring to Figure 5.1 and Table 5.1, the last four constructs of MSLQ are scores for the learning strategies section: organization, critical thinking, effort regulation and help seeking. All four scores increased significantly. The increase in organization and critical thinking scores indicate an increase in cognitive and meta-cognitive component, which means that students had improved their thinking approach through connecting and representing knowledge to better understand, and making justified judgments as well as to transfer and apply knowledge in a different context. The increase in effort regulation and help seeking scores indicate an increase in resource management strategies, which means that students had increased their persistence in pursuing their learning goals even in the face of difficulties or boredom, and enlisting the support of others by properly utilizing resources and actively pursuing assistance. This statistically proved that, after going through CPBL process for one semester,

(iv). Students do improve their learning motivation and their employment of learning strategies that will enhance their problem solving skills.

5.2.3 Factor 3: The Students' Team Working Skills

Team Working Effectiveness Scores (TWES) is used in the research to study the improvement of team working skills among engineering students in solving team-based problems. This research defined effective teams by three characteristics which are interdependency, goal setting, and potency.

- Interdependency means teams that have cooperation among team members to accomplish a task.
- Potency means teams that have shared belief that they can be effective.

- Goal setting means teams that set goals and sub-goals to accomplish a task.

The first research question is quantitatively studied by examining another sub-question which is the fifth research sub-question. The sub-question is:

(v). Do students improve their effective team working skills which lead to enhancement of problem solving skills?

As shown in Figure 5.1, all the three characteristics score higher at the end of semester as compare to the beginning of the semester. Table 5.1 also shows Wilcoxon Signed Ranks Test that is used to determine is there significance differences in team effectiveness attributes at the beginning of semester and at the end of the semester. The study shows that there is significant difference of all the characteristics, with all the respective effect sizes (r) are considered large. Therefore, the test shows that the students' interdependency has increased. This indicates that they have 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 within teams. As shown in the potency score, the students' confidence levels toward their team have also increased. They have the shared belief that they can effectively solve a given problem together, thus improved their effort and motivation. The test also shown that the students' goal setting have also enhanced significantly toward the end of the semester. It means that the students strongly believed that their team has a common objective and goal, thus improved their confidence in solving any complex problems together. The result informs the finding of Moore (2006) when she studied the effect of team working on problem solving through model-eliciting activities (MEAs), which shown a positive correlation in all the three measures. MEAs is a method to teach modeling to engineering students.

The result of this study statistically proved that, after going through CPBL process for one semester,

(v). students do improve their effective team working skills which lead to enhancement of problem solving skills.

5.2.4 Factor 4: The Students' Problem Solving Assets

Problem solving assets is a set of qualities that a solver has when solving a problem. The assets are classified into three aspects: (1) knowledge, (2) confidence, and (3) cognitive process.

- Knowledge is depth of understanding associated with content that the solvers have.
- Confidence is about the problem solvers belief, expectation and motivation. It is what the solver expects and believe is important and useful about himself/herself and about the problem.
- Cognitive process is about actions (both overt and covert) that the solver does while engaging in problem solving.

In CPBL, problem solving assets is considered as the outcome of the process that students went through. It is expected that, upon going through CPBL process, students should enhance their knowledge, confidence and cognitive process. Thus, the first research question is quantitatively studied by examining another sub-question which is the sixth research sub-question. The sub-question is:

(vi). Do students become better problem solvers in terms of acquiring their problem solving assets?

Figure 5.1 and Table 5.1 summarized the results of the question. As shown in the figure, at the end of the semester, the EPSI scores for all problem solving assets increased. As statistically illustrated from the results of the paired t-test given in Table 5.1, all EPSI scores in problem solving assets increased significantly. The EPSI scores show the degree of enhancement of the students' deep thinking. Therefore, in terms of enhancement of deep thinking, the students' knowledge, confidence, and cognitive process have improved significantly upon attending a course that used CPBL.

As shown in the table, the effect size of all the elements are greater than 0.8, which indicates that the CPBL teaching methodology had great effect upon the students' deep thinking of all the assets. The students' deep thinking upon knowledge, confidence and cognitive process has improved significantly. This means that the CPBL approach in learning does have greater impact on the students' problem solving skills. The students acquired their knowledge that was composed of many components such as facts, concepts, methods, and planning. This is a key feature in problem solving. They improved their confidence by recognizing their strengths and weaknesses, and be internally and externally motivated. They have also improved their cognitive processes while engaging in productive problem solving. This means that the CPBL approach in learning does have greater impact on the students thinking. This statistically proved that, after going through CPBL process for one semester;

(vi). students do enhance their problem solving assets to become better problem solvers.

In this study, the enhancements of engineering problem solving skills through CPBL are categorized based upon all these four factors: the students' problem solving elements, the students' motivation and learning strategies, the students' team working skills, and the students' problem solving assets. After going through the CPBL class for one semester, all these factors are significantly improved. Therefore it can be concluded that upon attending CPBL class for one semester, students enhanced their engineering problem solving skills. But, how did this happen? The answer lies upon the following results.

5.3 Research Question 2: How the CPBL model developed problem solving skills in engineering students?

The second research question leads to the explanations on how the CPBL approach developed engineering problem solving skills among engineering students. To answer this research question, qualitative methodology is used. The results of the analysis are based upon themes that emerged from interviews and a series of students' reflections. The investigations are based upon four spotlights which are problem solving elements, students' motivation and learning strategies, team working effectiveness, and students' problem solving assets.

5.3.1 Spotlight 1: The Students' Problem Solving Elements

With regards to students' problem solving elements, many related themes emerged from students' reflections and interviews. It shows how the students enhanced their problem solving elements as a factor of enhancing their problem solving skills. The themes are classified into 5 categories; (1) problem identification, (2) problem analysis and synthesis, (3) solution generation, (4) self-directed learning, and (5) reflection.

In CPBL, during problem identification students will brainstorm their understanding of the problem to reach a consensus of the problem statement (Mohd-Yusof and Helmi, 2010). At this stage problem acts as a stimulus to enhance students' curiosity. Many themes emerged belong in this category. Among them, the popular themes which are based upon the most frequent mentioned by the students, are understanding in associated with problem restatement and problem representation, followed by learning issues, then team peer teaching, confuse, overall class discussion, reflection and self-directed learning, respectively. However, there are two other themes that can be classified in this category, which are problem restatement and problem handling. Since these themes were not saturated, they cannot be considered in the result presentation.

The most frequent theme is how students emphasized their enhancement in understanding upon going through problem identification in the CPBL process. For example, one of the students joyfully mentioned "I was so happy that I started to love programming part. I even helped other groups that seek for my help to identify their problem." To understand a problem is the most important part in problem identification. This is where the students properly begin problem solving by understanding and analyzing the actual problem, thus preventing them from rushing to find the solution. It is where students connect their prior knowledge and experience to the problem as stimulus for learning. In CPBL, since the problems are open-ended and ill-structured, to really understand the problem is very crucial and challenging. Thus, with proper guidelines and practices in CPBL, students will enhance their understanding in problem identification.

Another most frequent concerned for problem identification is matters with regards to learning issues. Learning issues are new knowledge that must be learned to solve a problem (Mohd-Yusof, et.al., 2011). For example, one of the students mentioned that, “our first meeting was on the learning issues that we have discussed in the class. In order to have an effective meeting what we did was to read on all the learning issues and just focus more on one particular topic.” In CPBL class, usually there will be a slot of overall class discussion to discuss and have a common agreement and understanding of the learning issues. To learn the issues, students will distribute their peer teaching load among their team members.

Another important factor in problem identification that was frequently mentioned by students is team peer teaching. Team peer teaching is an element of cooperative learning where students teach each other. With regards to this, one student commented his knowledge retention. He stated during the interview that, “discussions in a team really help me a lot where we can teach them and learn with them. It actually gives me a long duration to remember what I have learn, because before this after I learned by my own and do not discuss to anyone, by a week, I couldn't remember what I've just learned before.” As mentioned by the student, with team peer teaching, students will have longer retention of what they learned. Furthermore, through team peer teaching students will have better understanding of the material because they learn with a view of sharing. Peer teaching is essential in developing skills to learn in students, especially on technically challenging material, where they would easily give up if they were to study alone. Students explain what they understand to teach team members while learning together, and discuss the questions or unclear concepts before coming to class for the overall class peer teaching and learning session.

Regarding problem analysis and synthesis, among the most frequent theme that emerged is ‘understanding’. For example one of the students highlighted that in this CPBL class, “I always explore my thinking out of the boundary way”. It shows how the course nurtured the students’ critical thinking skills in their problem analysis and synthesis. Other most frequent themes emerged is analysis and synthesis itself, as stated by one of the students regarding analysis, “we analyze each of the graphs and try to get the data needed.” An example of synthesis is as stated by another student, “Now I know how to integrate!” This statement was a kind of “appreciation” by a third year student, as if before this course, she had never learned how to synthesize. In CPBL, during problem analysis and synthesis, all collated information and knowledge is shared and critically reviewed. Then the relevant ones are synthesized and applied to solve the problem. This step can be iterative, where students need to re-evaluate the analysis of the problem, pursue further learning, reporting and peer teaching. Usually, at this point students actively participate in the e-learning forum designated for the problem.

In solution generation, overall class discussion is the most popular theme that emerged. As appreciated by one of the students, "I love to have those kind of participation given by other groups because when we discuss we can see many different things and even “new” theories coming out. It is funny but as well effective.” During the overall discussion, students exchanged their ideas as well as exercised their thought. At this point students should demonstrate their mastery of knowledge.

Understanding is another popular theme which emerged in solution generation. As mentioned by one of the students, “But the most interesting part is when completing final phase. That is the time where I can connect all the knowledge to one small design. I know where to begin and what to do.” This demonstrated the maturity of the student in solving a complex problem as she went through CPBL. In CPBL, to enhance students’ understanding, connections between concepts and applications in other areas are discussed usually during the closure. This is necessary to widen the views and generalize the knowledge transfer for other types of applications, thus strengthening students’ understanding. It is also important to tie up loose ends to avoid feelings of dissatisfaction among students.

When reflecting solution generation, one of the students mentioned that, “the tedious part is, sometimes it really hard to reach to one final answer because all have different views on the topic that we discuss. At the end of CS1, I felt that our group can do better than that.” Reflection in solution generation is another theme that frequently emerged. Reflection in solution generation is very important exercise for the students, as it is used to improve their problem solving process when they face different problems in the future.

Another two important problem solving elements as extracted from the interviews and students' reflections are self-directed learning and overall reflections. Regarding self-directed learning, a student noted that, "on my learning process, it proves that I can be independent to get new knowledge. It is only the matters to get the confidence within myself and the place to seek for verification of the idea that passes my mind. For that, what I did in the class was to ask question in the overall class discussion". Self-directed learning means students assume major responsibility for the acquisition of information and knowledge. Since CPBL is student-centered, upon attending the course, students developed their confidence in self-learning that will enhance their skills in acquiring information and knowledge as very essential elements in solving problems.

Reflecting upon the overall learning experienced that the students acquired are another important elements in problem solving. As reported by one of the students, "before this I just read and then I don't know where to integrate and then, how to integrate. Now I know how to integrate, rather than just study". From reflections, students recognized their strengths or weaknesses, thus they know what to do next in order for them to improve their problem solving skills. In CPBL, reflections are assigned individually or team-based. Initially, prompting questions are provided as scaffolding for students to do a good reflection. Students are guided to internalize what they have learned and develop meta-cognitive skills. Meta-cognitive skills are essential for life-long learning and for students to understand themselves as a learner, and as part of a community. By the end of the semester, most students learn to internalize not just knowledge, but also the process that they went through to develop their skills. In addition, as part of continuously improving themselves, they were also able to identify aspects that need improvements.

Figure 5.2 shows the open, axial and selective coding of the problem solving elements analysis. Since all problem solving process involved reflection and self-directed learning, apart from the overall reflection and self-directed learning, these two terms are considered as the axial coding.

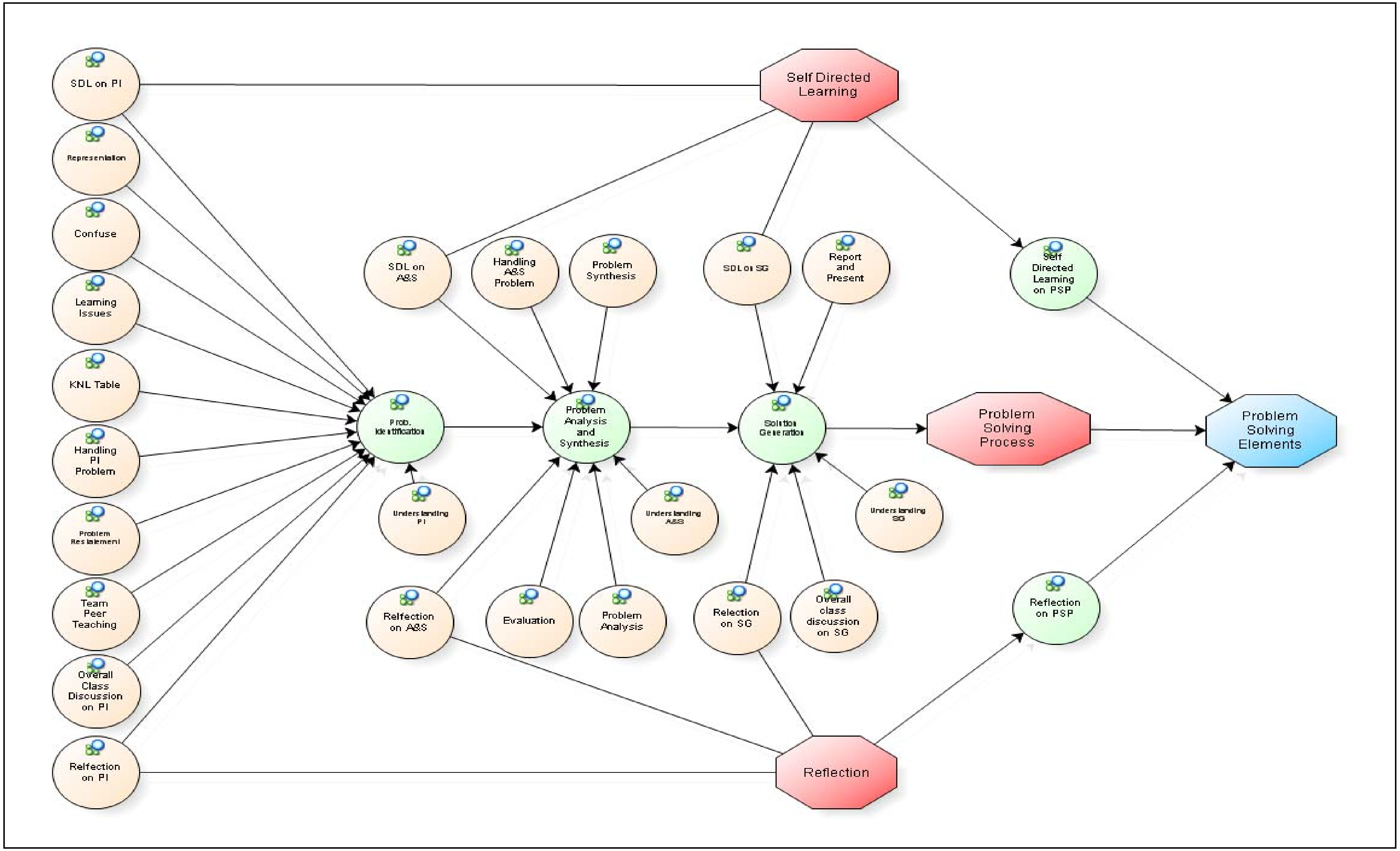

Figure 5.2: Open, axial and selective coding for sub-model enhancement of engineering problem solving elements

The selective coding is named as the problem solving elements which is the integration of the problem solving process, reflection and self-directed learning. This concept is illustrated in Figure 5.3. This sub-model shows all the related elements and the process that involve in how students enhance their engineering problem solving skills

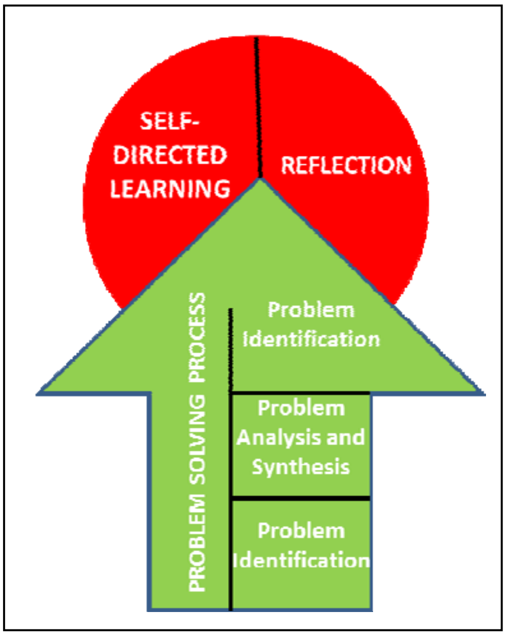

Figure 5.3: The problem solving elements

5.3.2 Spotlight 2: The Students' Motivation and Learning Strategies

Students' motivation and learning strategies play very important role in driving learning. It is one of the main bases for engagement in any activity, whether a person decides to spend his time and effort on a certain task. PBL had been shown in several studies to shape attitudes and motivate students to learn. Students were found to be more positive towards learning compared to those undergoing traditional lectures, and hence it is not surprising to see them develop challenging skills such as problem solving. The learning environment within the CPBL approach is in accordance to the expectancy-value theory. Expectancy-value theory states that students choose to engage in a task that they expect to succeed in, and that they deem to be beneficial if they completed the task successfully.

How the students enhance this motivation and learning strategies upon going through CPBL is shown here. In this study, the two most frequent themes in motivation are intrinsic goal orientation and expectancy, respectively. This is then followed by extrinsic goal orientation. Upon undergoing CPBL for one semester, the students' motivation in learning is driven by their intrinsic goal orientation. As stated by one of the students, "I won't be able to learn a new thing if I easily give up trying and learning from mistakes. We learn from mistakes. If I keep on trying and am persevering, then eventually I will be able to master the things I am learning." This statement illustrated the intrinsic value component of the student's goal orientation, as she emphasizes her effort of not giving up due to her quest for knowledge. The next most frequent theme in motivation is expectancy. The expectancy component measures students' expectation for success in a course. This is mentioned by one of the students, as she said, "I realized that if all of us contribute our parts during discussions, the outcome will be better as there are more ideas being generated." She highlighted that in order for her to succeed in the course, she need to contribute more in group discussion. As for the extrinsic goal orientation, a student stated that "As overall, I am very happy to have a great time during this class although sometimes I have a hard time. Lastly, for sure I need to get A in this subject." She concluded her statement of happiness and working hard with her expectation to get the best grade for the course. This extrinsic goal orientation will motivate her to work hard and finally achieved the reward of her expectation.

In this study, intrinsic goal orientation is mentioned more than extrinsic goal orientation. This shows that students are more into the problems with curiosity, as a challenge to master their understanding compared to their grades and rewards. Though, both are considered important for them. Another important theme that emerged in the reflections and interviews is task value, for example, one of the students stated, "As for Simulink, it was totally new to me. It was fun and interesting, seeing how graphs can be produced and learning how to analyze the graphs." This statement shows the degrees to which the students perceive the course material in terms of interest, significance, and usefulness. All these statements show the students' learning motivation, which are very important pre requisites to overcome and sustain the challenges in solving complex and open-ended problems such as the problems in CPBL.

The enhancements of students' learning strategies can be understood from important themes that emerged in students' reflection and interviews. Among all the themes, help seeking is most frequently mentioned. In fact, it is the most mentioned in this spotlight. Help seeking is about enlisting the support of others. As one of the students reflected, "When we are discussing about certain topics, we help each other to understand the topic better." This shows how the students properly utilize resources and actively pursue assistance to enhance their learning strategies. The next most mentioned theme is effort regulation, as revealed by one of the students, "First we need to study like mad people and then vomit it out to our team mate then only the real thing will come, a clearer picture of the content. It actually happens on all the four phases where we don't know anything but at last produces something." This shows how the student was persistent in pursuing his learning goals even in the face of difficulties or boredom. Both of these themes, help seeking and effort regulation, indicate how the students enhance their resource management strategies as an important element in learning strategies.

Other important themes that also emerged in this analysis are critical thinking and organization. An example of critical thinking which emerged through overall group discussion, a student revealed that, "with more feedbacks and comments, the original solution is improved and made better, and eventually the problem can be solved in a better way." The statement shows how the student's problem solving skills is enhanced through the CPBL process. Organization refers to making connections between substances to be learned. With this regards, one of the students mentioned that, "looking at the syllabus, I noticed that I can see the connection of all the 3 phases. Problem statement must be clear before confronting the problem." The emerging themes of organization and critical thinking indicated the use of cognitive and meta-cognitive component in problem solving. It shows how the students improved their thinking approach through connecting and representing knowledge to better understand, and making justified judgments as well as to transfer and apply knowledge in a different context.

Figure 5.4 shows the open, axial and selective coding of the analysis. The elements of motivation strategies and learning strategies are considered as the axial coding that group all the themes into two categories. The selective coding is designated as motivation and learning strategies, which is the integration of the motivation strategies and the learning strategies, since both are closely inter-related to one another. This concept is illustrated in Figure 5.5. This sub-model shows all the related elements and the process that involve in how students improve their learning motivation and their employment of learning strategies that will eventually enhance their problem solving skills.

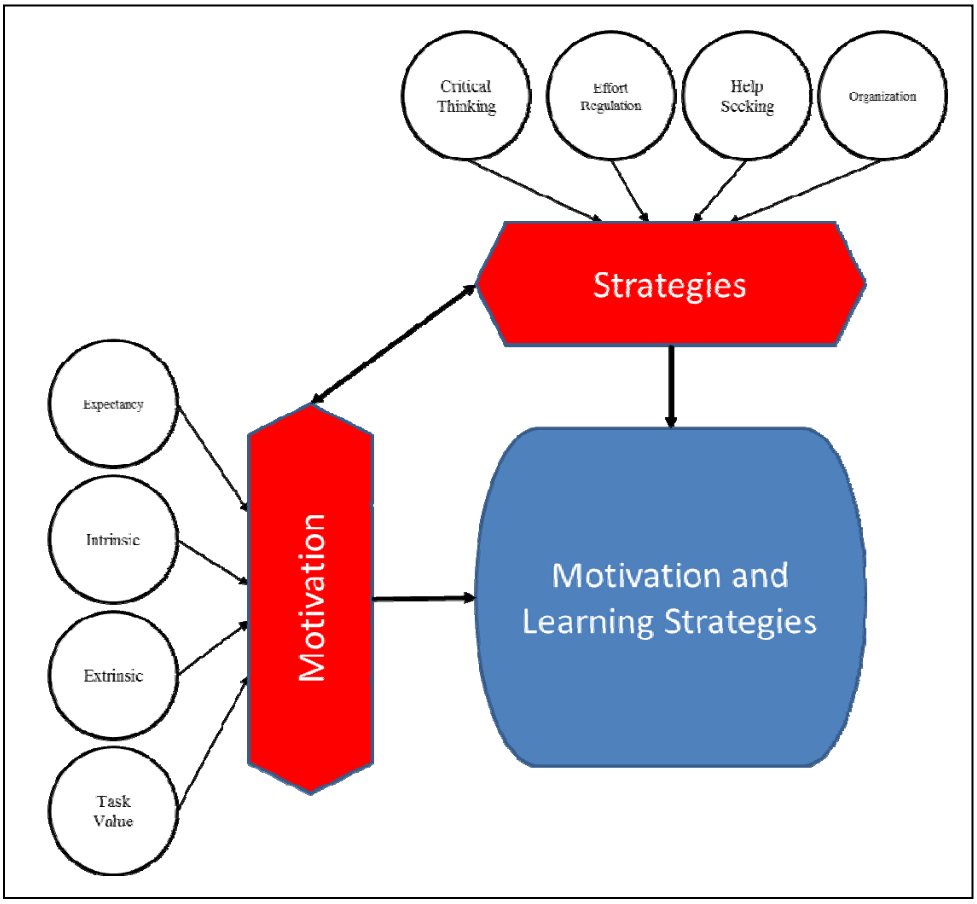

Figure 5.4: Open, axial and selective coding for sub-model enhancement of engineering problem solving skills (motivation and learning strategies)

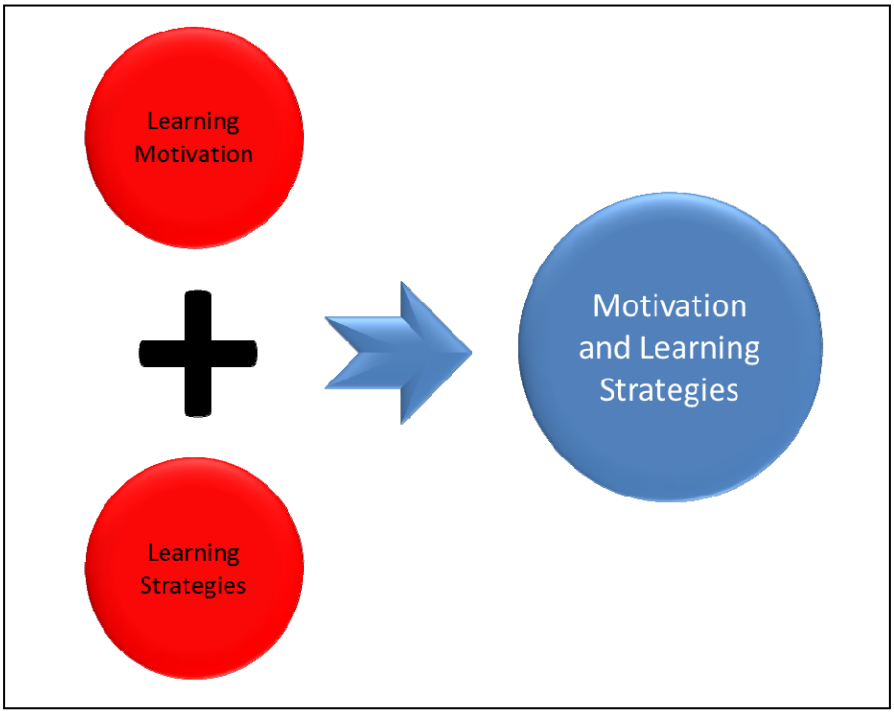

Figure 5.5: Motivation and learning strategies

5.3.3 Spotlight 3: The Students' Team Working Skills

How do students enhance their team-based problem solving skills in CPBL? The analysis from students' reflections and interviews revealed five categories of themes. Altogether, 10 themes emerged from the analysis, with 9 of them considered as important since there are saturated. The categories based upon the five CL principles as in Johnson, Johnson and Smith (2002) are interpersonal skills, interdependence, face-to-face interaction, individual accountability, and regular self-assessment.

Themes that emerged in the analysis classified as interpersonal skills are conflict management, communication, and leadership. The most mentioned is conflict management, followed by communication, then leadership. All these themes are considered important. An example of conflict management, on trying to build his friends' trust back after a small conflict, one of the students remarked the following:

"In case study 3 I tried my best to win my teammates' heart back. What I had tried was not just for them, it also for myself. I tried what I could do for the case study 3. I had participate all the meetings and learned deeper of the tuning. Yeah! I could help my team to solve some of the problems. I think I had improve my attitude if compare with case study 2."

When teams become matured, it develops trust. Poor teams will try to ignore conflict hoping that it might go away. Good teams will change conflict into opportunity, because from conflict will come better decisions (Woods, 2000). In CPBL conflict cannot be avoided. But, the beauty is, students learned how to manage it!

Another theme in this category is communication. Good communication is vital in interpersonal skills. A basic skill for effective interpersonal skill is the ability to listen and respond (Woods, 2000). Communication is the heart of effective teamwork (Smith and Imbrie, 2004). Through CPBL students learn to communicate extensively, especially during team discussion, peer teaching, and overall class discussion. As one of the students revealed her enhancement in the skill, "I managed to pick up the skill to make others to talk or to initiate a conversation." Another frequently mentioned in the reflections and interviews is enhancement in leadership, thus, developed the students' interpersonal and problem solving skills. In The Leader's Handbook, Scholtes (1998) listed six "New Competencies" in leaders. The second competency is that the leaders should have the ability to understand the variability of work planning and problem solving. The fourth competency is that the leaders should understand people and why they behave, i.e. the interpersonal skill. With regards to this, one of the students said, "perhaps I would love to master the art of saying the not so good things in a good way", which reflected the tendency of the student to acquire one of the characteristics of effective leadership skills.

The next category of theme is interdependence. Three themes emerged in this category. The themes are shared value, tolerance and commitment. All these themes are considered as important since all are saturated, with commitment mentioned the most, followed by shared value and then tolerance. Interdependence is about learning how to work together, with then producing better results in solving team-based problems. A very important element in interdependence is commitment. This theme emerged several times in the reflections and interviews. An example of commitment is as stated by one of the students, “In my team, everyone cover up every weakness in others to make our team complete. Here, all the students in the team are very committed in helping each other to ensure they achieve high performance team, and together they will produce good results. The following statement is proclaimed by one of the students that emphasized the shared value among her team;

“Overall, I am satisfied with myself and my team performance and I feel that my team is a Cooperative Learning Group. All my team members willingly spend their weekend to finish the report of Case Study 2 and they are full of commitment. We work as a team and I can say that ‘if you jump, I jump and we jump together’.”

The last statement in the vignette, “We work as a team, and if you jump, I jump, we jumped together” really illustrated the form of sharing among the team members. The last theme that is also important in this category is tolerance. Differences are routine aspects in almost every situation. Be it in the students’ learning styles, genders, races, religious or thinking skills. To be interdependence ones need to understand and tolerance with each other. In problem solving, an ill-structured, open-ended problems solved by smart and motivated students routinely they disagree about the best way to accomplish the tasks and about how to deal with trade-offs among priorities. In this heated discussion, tolerance is highly required to let the problem solved constructively. With this regards, one of the students reported that, “At first, we were just like a traditional group, but doing a little more than a traditional group. But as time goes by, we improved and performed better, and were more like a cooperative team. We shared with each other and worked with each other. From there, we learnt from each other. Though we are all of different backgrounds, we still worked together very well. I hope this can be a preparation of what I am going to face when I am working.” In CPBL students learned to be tolerance. But, it will take some as time and progressively improved. With scaffolding and correct facilitation students can performed well working in a group. As mentioned by Smith (2004), there are 4 levels of performance groups. Once need to improve from pseudo-groups to high-performance cooperative groups. At the high-performance cooperative groups members have mutual concern for each other's personal growth that enable them to perform far above expectation (Smith, 2004).

In face-to-face category, theme that emerged in the analysis and associated to it is discussion. In the analysis, there are numbers of vignettes belong in this theme. Therefore it is highly important. Below is one of the vignettes from one of the students:

"I assumed that actually I can determine the control configuration of the loop by looking at the P&I Diagram. If it measured the variables before entered the valve, I assumed it was feed-forward and if it measured the variables at the exit of valve, it was feedback. After discussion in our meeting, I was exactly wrong."

Discussion is very important as it enables the verbalization of thought, forcing ideas to be organized logically. Verbalization also makes thinking visible, enabling critical examination. This exercise in thinking process often results in better solutions to problems. At the same time a lot of problems happened because of communication breakdown. In CPBL, discussion is the essence of cooperative learning. Students were trained to have positive and deep discussions at every phase and every cycle of CPBL process, from problem identifications, peer teachings, overall class discussions until result presentations. Face- to-face interaction is not only among the students, but also with facilitators and invited experts form industries. Forum post in e-learning is one of the means used in CPBL to enhance the discussions, as well as creating a learning community.

Another category of theme is individual accountability. There are 2 themes considered as important in the analysis, which are learning and time management. With regard to learning, one of the students reflected, "After discussing in team, standard block diagram was used instead of following the process in the diagram. I do my study on block diagram after meeting with teammates again. It make stronger concept to me after revision was done." CPBL is student-centered learning, where students are responsible on their own learning. With peer support and probe by a facilitator, students were trained to be self-directed learners. In peer teaching, students not only have to learn, but also to teach one another. Learning to teach will definitely enhance individual accountability. Time management is another theme that is classified in this category. As one of the students explained how she managed her time, "Then, our first case study came out. I cannot manage my time because of too many things to do. To prevent the time management problem, I included our discussion in the time table. I fixed the time. So that, I will prepared well before attend the meeting and class." CPBL trains and requires students to manage their time well. Be it in class or outside of class. Students realize that procrastination will definitely jeopardize not only the CPBL course but also others. It is not that CPBL consumes a lot of work, but it is about how someone managed their time.

The last category of effective team working is regular self-assessment. The themes emerged that belong to this category are peer reviews and reflections. However, though peer review is considered as an important factor in assessment, it is very seldom mentioned by the students. Since it is not saturated, the researcher has to omit this from the finding. Formal reflections usually are done at the final stage of CPBL cycle. However, along the way students are encouraged to reflect upon and be cautious of their decisions at every stage of CPBL process. During reflections students will reflect on their problem solving process and their performance as a team player (Tan, 2003). This is in line with what one of the students mentioned in her reflection, "We started our serious discussion about shower control system. I gave my opinion but I'm still afraid to deny their opinion although I didn't agree with their opinion. That was my weakness. I still thought they are better than me. Then, they always right. Totally, I am wrong." With regular self-assessment, for example, through reflections, students will evaluate themselves, and improve upon whatever weaknesses that they have. They might also do the comparison between themselves and their team member, so as to gauge their ability, performance or attitude for self-evaluation and improvement.

Figure 5.6 shows the open, axial and selective coding of the analysis. The five elements mentioned above are grouped into an axial coding named the CL principles. Interpersonal skills and face-to-face interaction are grouped into an axial coding called potency; while regular self-assessment and individual accountability are grouped into an axial coding named goal setting.

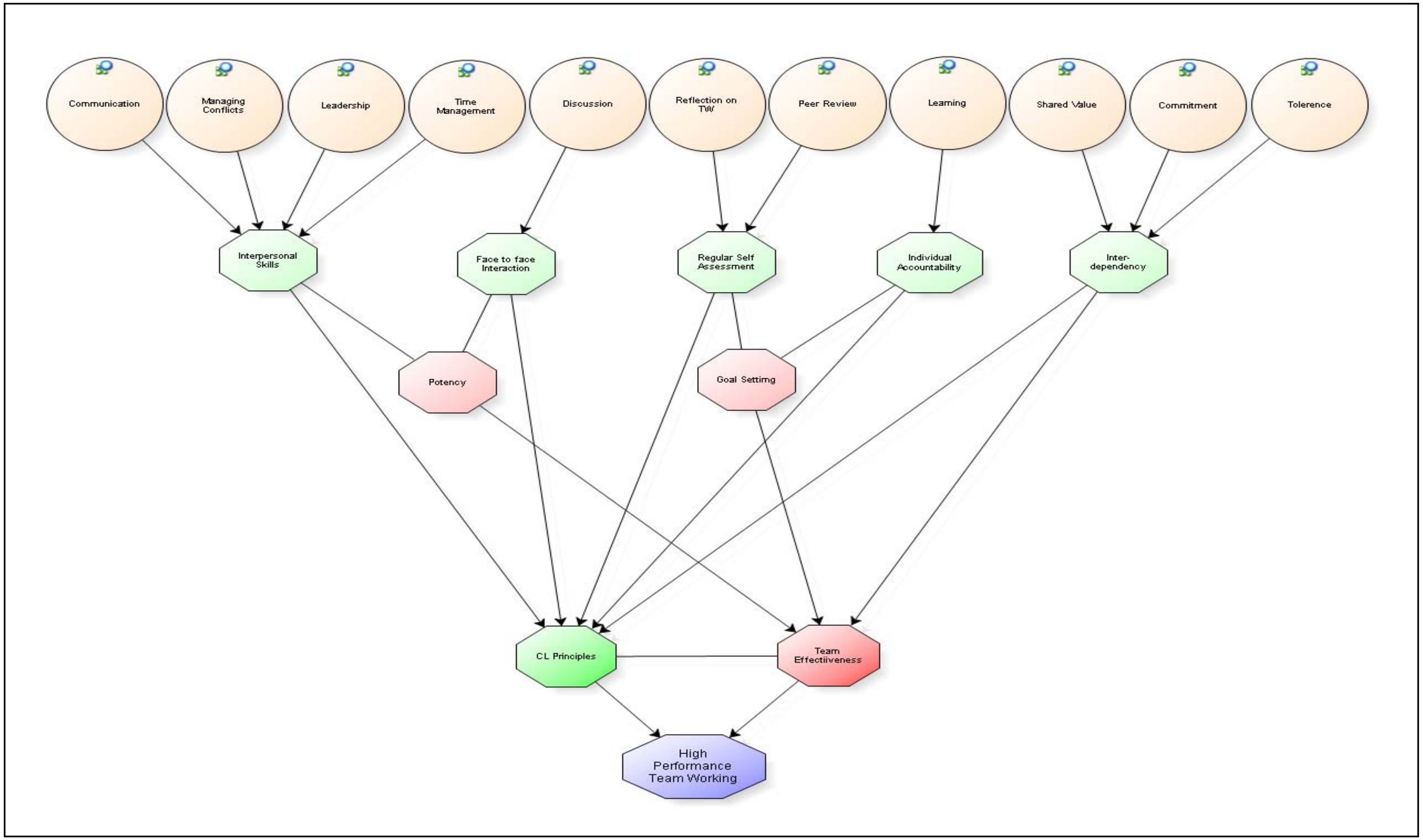

Figure 5.6: Open, axial and selective coding for sub-model enhancement of engineering problem solving skills (high performance teamwork)

The potency and goal setting axial coding plus element of interdependency formed a new axial coding which is team effectiveness. The selective coding is named as high performance team working which is the integration of the CL principals and team effectiveness. This concept is illustrated in Figure 5.7. This sub-model shows all the related elements and the processes involved in how students could achieve high performance team working which leads to the enhancement of students' PS skills.

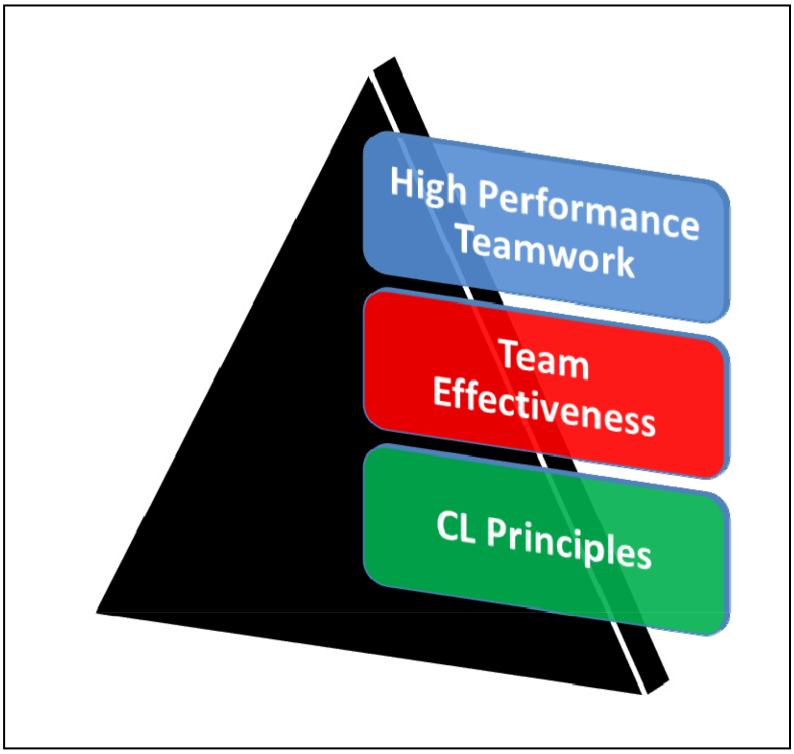

Figure 5.7: High performance teamwork

5.3.4 Spotlight 4: The Students' Problem Solving Assets

Problem solving assets are resources that problem solvers have to solve problems. Upon going through CPBL course, it had been proved that there is significant evidence that the students had improved their problem solving assets. The question is how did it happen? The answer to this question is highlighted in this section.

The answer is based upon the interviews and series of students' reflections. Themes emerged in the category of problem solving assets is divided into three major divisions; knowledge, confidence and cognitive process, which is in line with Adam (2007) and Mayer and Wittrock (2006). Knowledge is depth of understanding associated with content that the solver has. It could be facts, concepts, methods or procedural. Confidence is the self-belief, the expectation and motivation that make all the difference, not only on how students approach problems, but also the problem's difficulty level. If students think the problem is hard when it is not, they will do worse than if they have the confidence. Cognitive process is about actions (both overt and covert) that the solver does while engaging in problem solving.

Themes that emerged in the knowledge category are concept, facts, procedural, retention, strategy and understanding. The emerging themes are very much in line with many studies such as Adams (2007), Mayer and Wittrocks (2006), Schoenfeld (1987) and Polya (1945). The popular themes emerged as knowledge element in the study are understandings, strategies and procedurals. The rest are rarely mentioned by the students, and are omitted in this result. The most popular theme is understanding, followed by strategies, then procedurals. Understanding is the application of knowledge. One can have knowledge without understanding, but one cannot have the understanding without knowledge. For ill-structured, open-ended problems, understanding of the concepts is required to successfully solve a problem. One of the students reflected, "I would read on my own and then discuss among teammates to see that there is any misunderstanding and verification. If the verification can't be obtained than we will try to get it from the overall discussion." The statement implies the requirement of deep understanding as an asset to solve a given problem. In order to achieve that, the student read on her own, discussed among her teammates, then, if required, with the whole class during the overall class discussion. This is how the student enhanced one of her problem solving assets. Strategy is knowledge about planning, or series of actions taken to solve a given problem. One of the students mentioned, "When my teammates voice out their views, I will listen and try to think of some solutions or better ideas that might be helpful." Here, she was actively and deeply involved in the discussion. Strategically she thought of better solutions or ideas to solve a problem. According to Adams (2007), procedurals are knowledge of actions that are valid within a problem situation, such as algebraic manipulation. This procedural knowledge is formally trained in CPBL as revealed by one of the students, “During class, new method of learning is used. At first, it was difficult. Well, I’m not usually prepared before going to any class. But this class required us to learn ourselves. I’m not that good learning individually. But the approach was different. Learning issues are divided among team members, than we have to teach one another. I start taking it seriously because if our teammate fails to understand the topic, it means I fail. We have the responsibility to make sure our teammate understand it properly.” For CPBL students to successfully solve a given problem, they have to follow the CPBL procedure. Missing one of the CPBL steps, mean inviting failures in the implementations.

Confidence has a very significant influence on problem solving. However, it is often disregarded by researchers (diSessa and Wegner, 2005). In this study, themes emerged in confidence category are motivation, expectation, and belief, which is very much in line with what was proposed by Adams (2007). All the themes are very popular among the students, with motivation mentioned the most, followed by expectation, then belief. Motivation is about self-interest and desire to solve a problem, or to learn. To be a good problem solver, one needs to be highly motivated. One of the students reflected, “At the beginning of the semester, I was quite a passive person during discussions. Luckily, I have supportive teammates who always encouraged me and tend to ask me questions so that I would speak more. Then, I started to be more active to voice out my opinions.” Through cooperative learning principals embedded in CPBL, with the support from her teammates, the student’s motivation increased. She then becomes an active learner. Effective engineering team-based problem solving requires problem solvers to talk and voice out their thoughts and opinions.

Expectation is a presumption that someone will or should achieve something. One of the students remarked, “I might say that I am scare or busy but somehow I still produce what other produce and I hope that I produce a better result than others.” Expectation is very important in problem solving because it will drive someone to perform better and prevent them from giving up. Belief is an opinion about something that someone thinks is true (Hornby, 2005). It could be about self or about problem.

Belief about self is knowledge about owns self as a problem solver. Belief about problem is whether it is easy or hard, interesting or boring, etc. As stated by one of the students, “At the end of case study 1, I felt that our group can do better than that.” The statement is a form of “self-belief” that she can perform better, and “problem-belief” that the problem is not that difficult to be solved. Knowing oneself capability and problems’ difficulties effects degree of confidence to the problem solver. CPBL enhanced students’ belief through many ways such as self-directed learning, peer teaching, team working and reflection.

The third category of problem solving assets is cognitive process. It is a progression or strategies that problem solver takes to solve a problem. With respect to that, the following themes emerged from the interviews and students’ reflections: analyzing, discussing, executing, explaining, planning, questioning, researching, and representing. These themes are somewhat similar to what have been listed by Adam (2007), Mayer and Whitrock (2006), and Pretz, Naples and Sternberg (2003), Out of all these, the most mentioned are researching, followed by discussing, after that planning and then executing. The rest of the processes are not popular and will not be included in this result.

Researching means to study something carefully, such as through observation, reading or internet. When someone engaged into a problem and there is a gap between what she knows and what the knowledge required to solve the problem, then she has to do some research. As stated by one of the students, “Before team meeting, I googled the related learning issues around internet and reference books.” Unlike traditional lecture, CPBL starts with an unstructured problem that has more than one answer. Because there is a gap between what the students know and what knowledge is required to solve the problem, and furthermore there is no teaching in between, then they have to do some research on their own. Research is one of the important elements of cognitive process in problem solving assets. CPBL educate students to embark in research when starting to solve a problem.

Discussing is talking about something in detail by showing and exchanging ideas and opinions. In team-based problem solving, discussion is essential. People cannot read others mind. They need to voice out their thoughts and express their ideas. CPBL trained students to have positive and healthy discussions through group discussions, peer teachings, overall class discussions and community of learning with the use of forum posts in e-learning. As mentioned by one of the students,

"Talking about the content, we have covered the topic of control configurations and variables in a different way. I would read on my own and then discuss among team mates to see that there is any misunderstanding and verification. If the verification can't be obtained than we will try to get it from the overall discussion."

Planning is deciding a series of actions to solve a problem. As the adage goes, failing to plan, means planning to fail. PBL purist always said that PBL cannot work in a small group, in a medium to large class setting. Detractors of PBL tend to assert that PBL does not work at all. Actually part of it depends on how well the planning is in implementing PBL. In the CPBL model there are required steps to be taken in the execution. Missing any of the steps will cause failure in the implementation. Therefore it requires training, especially facilitation that is required for each of the CPBL phase.

With good facilitation, for example to include short talks on team working and time management at the beginning of the semester, the students' planning will be smoother. Without it, the students will feel lost and not motivated to prepare and properly go through the CPBL cycle. This can cause failure in the implementation. CPBL trained students to plan well their time, not only for the course but also for the whole semester. Students have to consistently learn and evenly distribute their work, otherwise, once lumped all at the end, students will feel that the work is a burden. It is not that there is a lot of work in CPBL, but it is because students have to be more serious and disciplined in their studies. One of the students stated the following;

"Then, our first case study came out. I cannot manage my time because of too many things to do. To prevent the time management problem, I included our discussion in the time table. I fixed the time. So that, I will prepared well before attend the meeting and class."

Another category of cognitive process that emerged in the analysis is executing. Executing is carrying out a plan using the appropriate method to solve a problem. With regard to this, one of the students reflected the following;

"What can I say about case study 2? Undoubtedly, it has taught me a lot of things. First of all of course the technical parts. I've learnt some new things which I have never come across before. The first thing should be deriving the models. Then, it should be learning how to make assumptions. Before, this, I used to make assumptions just as I like, without thinking of the reasons and the consequences of the assumptions. But now, I learnt that for every assumption that I make, I need to justify it and therefore, I can't just simply assume something. If I can't justify it, then the assumptions cannot be used since it might affect the models that I derive."

This statement is an example of how CPBL trained students to be good problem solvers in their executions of solution. Since problems are open-ended, there are many alternatives to a problem, which very much depends upon assumption that the students made.

Figure 5.8 shows open, axial and selective coding for enhancement of problem solving assets of engineering students. To be good problem solvers, students need to have all the three elements of problem solving assets. These elements are complimentary to one another. With sound knowledge, good cognitive processes and confidence, students can become good problem solvers. Deficiency of any one of these elements can cause immaturity of the problem solvers. Therefore, the axial coding are all the elements that integrated to one another, which consists of the related open coding. The selective coding is named the problem solving assets, which consists of all the elements. The sub-model of enhancement of the problem solving assets is as shown in Figure 5.9. It illustrated the integration of all the elements.

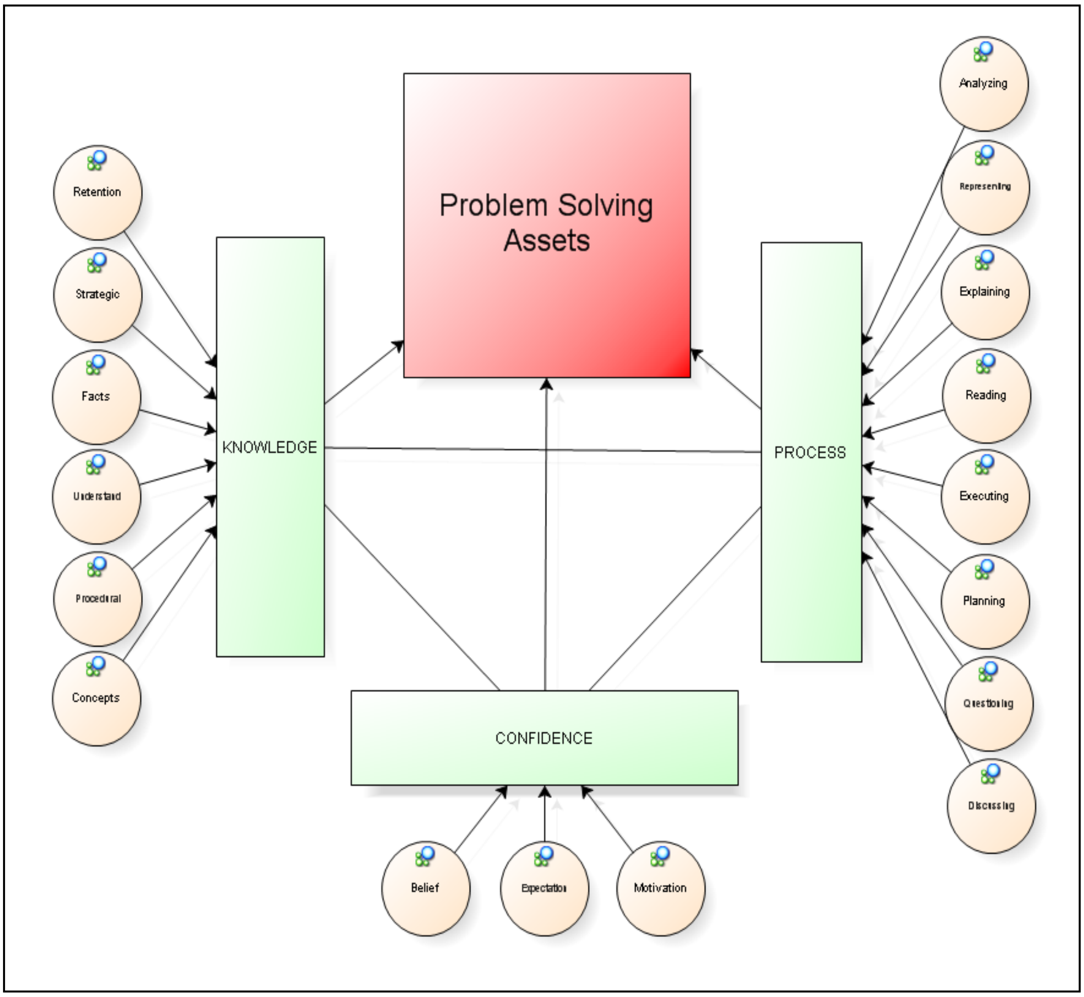

Figure 5.8: Open, axial and selective coding for sub-model enhancement of engineering problem solving skills (problem solving assets)

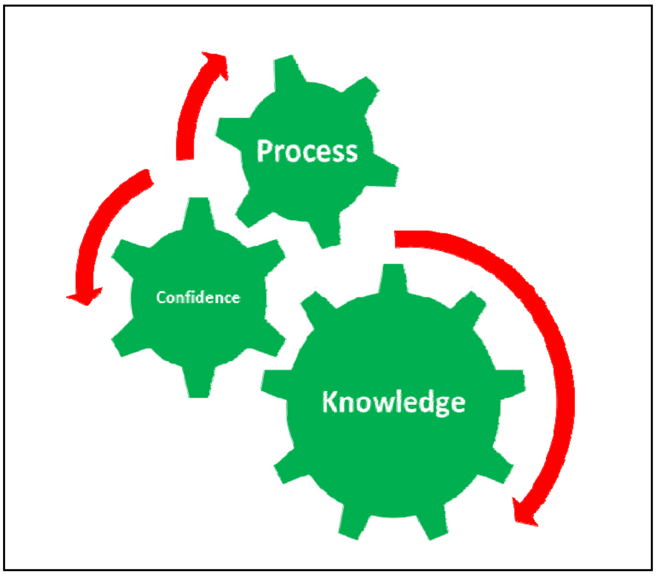

Figure 5.9: Problem solving assets

5.4 Enhancing Problem Solving Skills

The answer to the first research question calls for the second research question: How does it happen? Qualitative analysis is used in the explorations. Students were interviewed and series of their reflections were analyzed to find reasons for the problem solving skills enhancement. The themes emerged in the exploration are categorized under four spotlights to view the reasons behind the enhancements. The spotlights demonstrated how students improve their problem solving elements, motivation and learning strategies, and team working; which contributed a lot to students' problem solving assets, thus enhancing their engineering problem solving skills. The result from this qualitative analysis triangulated the quantitative analysis. Based upon the quantitative and qualitative analyses, the researcher beliefs that the enhancement of engineering problem solving skills through CPBL holds the following equations:

$$PSA = f(PSE + MLS + TWE)$$

Where:

PSA = Problem Solving Assets
PSE = Problem Solving Elements
MLS = Motivation and Learning Strategies
TWE = Team Working Effectiveness

Based upon the formula, the researcher proposes an integration of the sub-models which are shown in Figure 5.10.

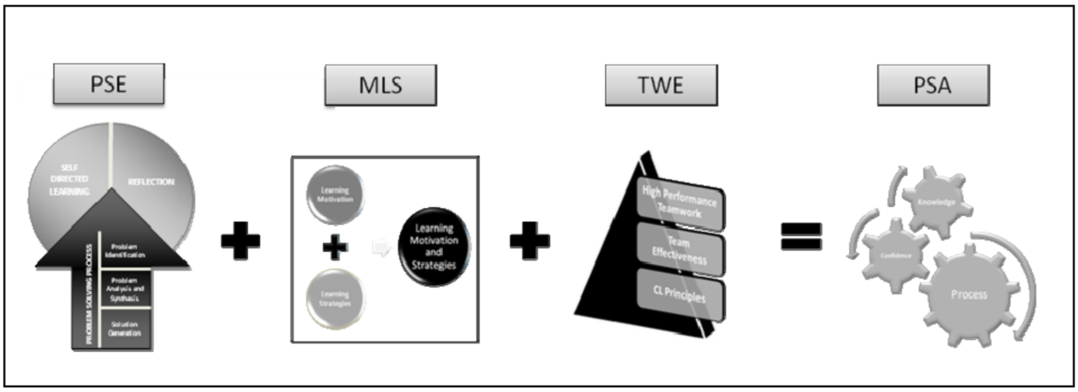

Figure 5.10: Engineering problem solving skills sub-models integration

5.4.1 Model Development

Figure 5.11 shows open, axial and selective coding for model development of enhancing problem solving skills among engineering students upon attending a course using CPBL approach. The model is developed using the four sub-models mentioned above. In this development, the sub-models are considered as open coding, which consist of problem solving elements, students' motivation and learning strategies, team working effectiveness and problem solving assets. The first three sub-models are considered as inputs to the model, while the fourth sub-model is considered as the output of the model. As shown in the figure the Problem-Based Learning (PBL) axial coding consists of (1) the problem solving elements, and (2) motivation and learning strategies. This is because in PBL, the problem is the starting point of learning. Problems crafted in PBL are open-ended and complex that highly require students' motivations and learning strategies. In PBL, self-directed learning is primary. Thus, students assume major responsibility for their learning, and acquisition of information and knowledge.

Apart from PBL, Cooperative Learning (CL) is another axial coding formed in the model development. This coding groups team working with students' motivation and learning strategies. In CL, with effective team working, students support and motivate each other in learning difficult topics and solving complex problems. CPBL is the selective coding which integrates both PBL and CL axial coding. It combines the benefits and advantages of both, CL and PBL learning methodologies, thus enhancing students' problem solving skills. The result of the enhancement is the acquisition of students' problem solving assets, which are knowledge, confidence and cognitive processes. This concept is illustrated in Figure 5.12. This model shows all the related elements and the processes which are involved in enhancing students' engineering problem solving skills.

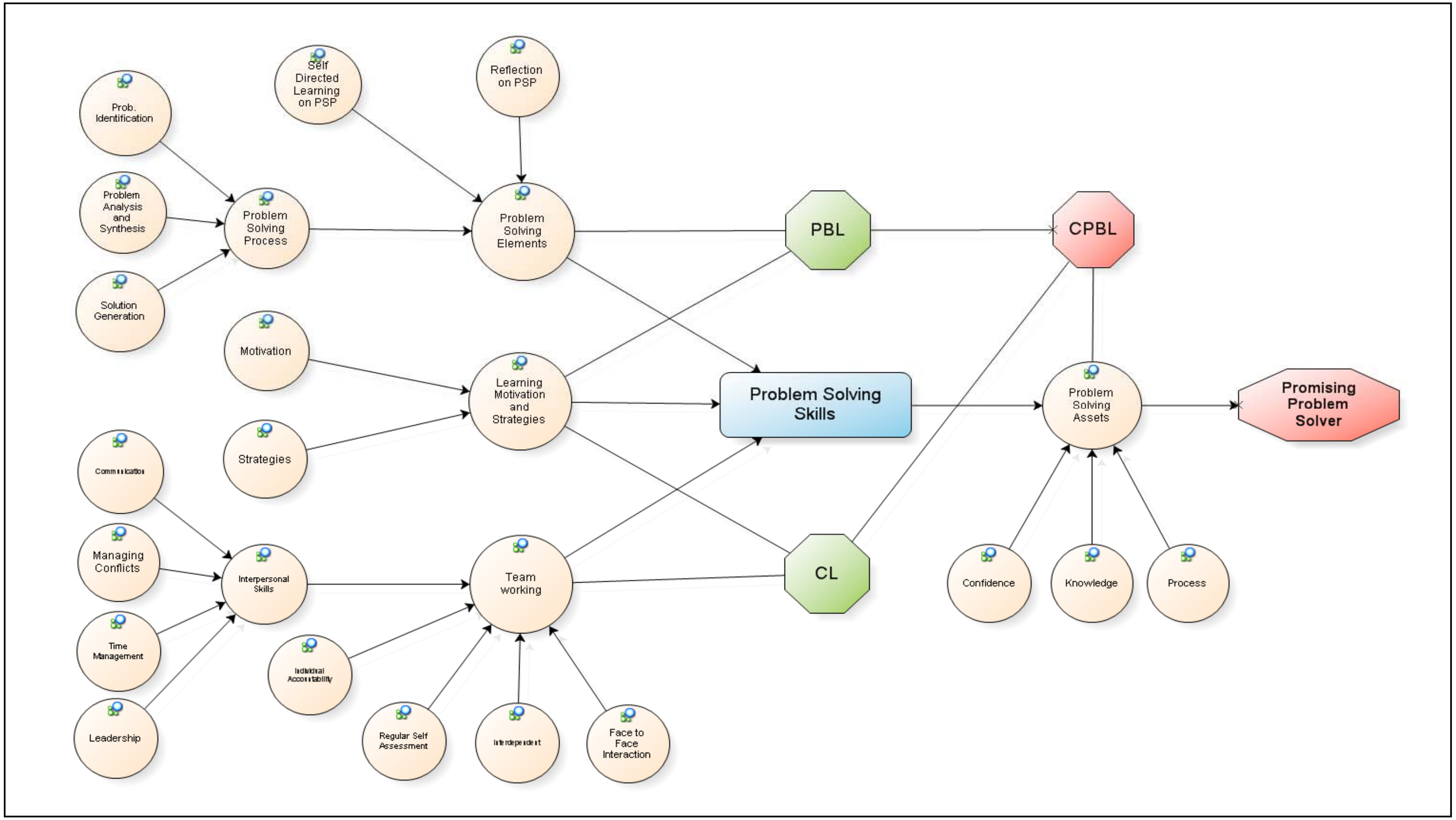

Figure 5.11: Open, axial and selected coding for model development of enhancing engineering problem solving skills among engineering students through CPBL

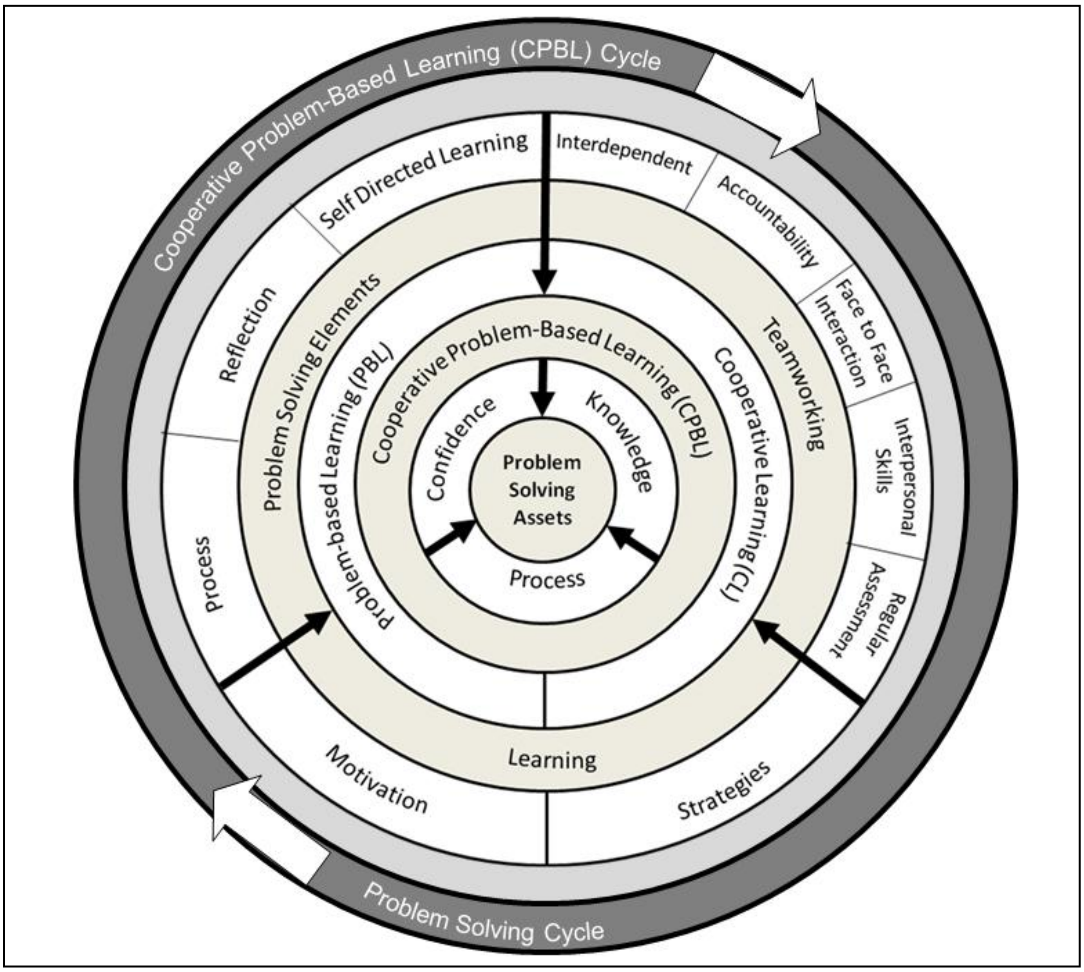

Figure 5.12: Model Development for Enhancing Engineering Problem Solving Skills of Engineering Students through Cooperative Problem-Based Learning

As shown in Figure 5.12, the enhancements of engineering students' problem solving skills through CPBL are governed by two important processes which are problem solving cycle and CPBL cycle. By exercising these two cycles, students are expected to improve their problem solving elements, which consist of problem solving process, self-directed learning and reflection. These three components are considered as vital elements to become an effective problem solver. An effective problem solver is the one who understand problem solving process, a good self-directed learner, and always reflects upon his steps taken throughout and after the problem solving process.

With these cycles, students are also expected to develop their motivation and learning strategies. From the beginning of the course, students' learning motivations are driven by problems posed onto them. They solve the problems not solely motivated by external factors such as marks and grades, but more of tasks to challenge themselves and to satisfy their curiosity. They are more inclined towards intrinsic motivations such as its usefulness and significance.

Since all problems assigned to students in CPBL are team-based, by solving problems together, students are expected to improve their team working skills. With their face-to face interaction, students tend to be more interdependent and accountable to each other, thus improving their interpersonal skills. Their peer reviews and reflections throughout their learning are forms of regular self-assessments that will provide feedbacks to develop and improve themselves, which are essential skills for their life-long learning.

As illustrated in the figure, elements of problem solving incorporated with motivation and learning strategies are the essence of PBL. While team working incorporated with motivation and learning strategies are the essence of CL. CPBL is the hybrid of CL and PBL. With CPBL, it is expected that the methodology will take advantages and benefits of both, CL and PBL, thus enhancing the students' problem solving elements, motivation and learning strategies, and team working skills.

The figure shows that, through this CPBL methodology, students are expected to improve their problem solving assets, which consist of knowledge, confidence and cognitive process. Knowledge includes factual knowledge, semantic knowledge, procedural knowledge and strategic knowledge. Confidence is the outcome of students' motivations, beliefs and expectations that could be internally or externally. Cognitive processing is something that students do while engaging in productive problem solving, for examples, building problems' representation, planning, analyzing, and executing.

5.5 Conclusion

In establishing the research background, it had been highlighted that the current technological growth, the explosion of information and knowledge, and the complexity of problems faced by today's and future engineering world call for the need to produce graduate engineers with sound professional skills. The most important professional skill 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, the Problem-Based Learning (PBL) is said to take the lead in enhancing students' skills of solving workplace problems (Strobel and Barneveld, 2009; Prince and Felder, 2007). By incorporating Cooperative Learning (CL), in which students actively and collaboratively involved in the learning process (Johnson, Johnson and Smith, 2006), in the PBL cycle, the Cooperative Problem-Based Learning (CPBL) is expected to exponentially enhance the students' problem solving skills (Mohd-Yusof and Helmi, 2008). Therefore, this research investigates the claim. By doing so, it also rigorously studied the reasons of the enhancement.

In establishing the research methodology, the enhancement of engineering problem solving skills through CPBL is based upon three major factors: (1) the problem solving elements, (2) the motivation and learning strategies, and (3) the team working effectiveness. Both, quantitative and qualitative analyses were used in the investigation and explanation. Here, the qualitative analysis served as a complement to the quantitative results. Pre-post tests were used to quantitatively measure the enhancement of problem solving skills. The EPSI was developed to measure improvements of the first factor as perceived by engineering students. The available MSLQ by Pintrich et al., (1993b) and the TWES by Imbrie, Maller and Immekus (2005), were used to measure the improvement of the second and third factors, respectively. As for the qualitative analysis, the research strategy followed the grounded theory approach. In this approach the research focused on students describing their experiences mainly through interviews and series of their reflections. The research had successfully analyzed the findings and presented the results.

The meta-analysis in Chapter 2 on future engineers and engineering education shows the importance of preparing graduate engineers to be self-learners, problem-thinkers and team-players. CL and PBL have gained prominence as methods of instructions to enhance these attributes (Smith et al., 2009; Duderstadt, 2008). As a hybrid model of CL and PBL, CPBL is supposed to upsurge the benefit. In CPBL contexts, all these attributes consist in the proposed definition of problem solving skills. Thus, the most important achievement from this work is it provides evidence that the CPBL teaching methodology does significantly enhance problem solving skills among engineering students. Since implementing PBL is a challenge, as contended by many researchers (for examples: Woods, 2000; Savery and Duffy, 2006; Prince and Felder, 2007) the research shows how the enhancement is achieved through the innovative model of PBL. While accepting the nobility of the work of Woods' (1997) with his McMaster Problem Solving (MPS) program, it is not easy to implement without institutional commitments. The MPS is an institutionalized program with series of separate, stand-alone "workshops" with heated debate on its transferability. The research found that the CPBL method resemblance the MPS, but in small-scale, content-based environment. It works well, even without institutional support or commitment. With this regards, based upon grounded theory, the researcher formulated problem solving skills equation and proposed a model development on how to effectively improve the skills among engineering students. This achievement has successfully responded to the call from Strobel's and Barneveld's (2009) on the need to study the effectiveness of PBL on students' performances, particularly problem solving skills. The following conclusions have contributed directly to the success of the work:

Firstly, from the meta-analysis of the requirement of today's and future engineers, problem solving, and students' learning, it can be concluded that success factors for enhancing engineering problem solving skills should be based upon (1) students' motivation and learning strategies, (2) team working, and (3) problem solving elements. Through problem solving cycles and CPBL cycles these three factors will lead to the enrichment of students' problem solving assets, which are the attributes of engineering problem solving skills.

Secondly, it can be concluded that the quantitative analysis has provided significant evidences that after going through CPBL in an engineering course, students do enhance their problem solving skills. This finding had proven that PBL can be effectively implemented, and in fact is a very powerful and effective method of learning for typical medium-size of engineering courses. Thus, the finding goes against the argument presented by Kirschner, Sweller, and Clark (2006) that PBL does not work. It also provides strong evidence that PBL does work in a small group, in a medium-size class setting, which goes against the believe of the PBL purists such as Singaram et al., 2008; Wee 2005 and Peterson, 2004.

Thirdly, it can be concluded that the qualitative analysis has shown how problem solving skills among engineering students achieved through CPBL. There are a few factors which contribute to the enhancement. These factors are categorized under four spotlights. The spotlights demonstrate how students improve their problem solving elements, motivation and learning strategies, and team working; which contribute a lot to students' problem solving assets, thus enhancing their engineering problem solving skills. This finding is very useful in providing guidance in designing PBL environment and facilitation of engineering students.

Fourthly, it can be concluded that the themes emerged in the exploration during qualitative analysis are governed by a set of equation that integrates all the factors contributed to the enhancement of engineering problem solving skills. This finding is useful to model relationship between all variables related to engineering problem solving skills enhancement.

Fifthly, it can be concluded that the answers obtained from the research questions show that the CPBL approach is suitable for implementation in a typical engineering course. The CPBL approach is an integration of CL into the PBL cycle based on constructive alignment. The qualitative analysis of the second research question shows that in each of the four CPBL phase, the teaching and learning activities and the assessment tasks allows learners to construct knowledge through their own efforts to learn, while harnessing the support of their team members and classmates. Results obtained show that efforts to ensure that the learning activities fulfill the five CL principles while undergoing PBL do promote the attainment of cooperative learning teams. Thus, the “power” of PBL can indeed be unleashed using a practical CPBL approach that is suitable for typical engineering courses.

Lastly, it can be concluded that based upon the developed problem solving skills equation, the study has successfully proposed a model for enhancing problem solving skills among engineering students. This model is very useful to illustrate the complex combination of CL and CPBL. It shows the integration of skills required in effective problem solving achieved though CPBL.

5.6 Limitation of the Study

This research has provided significant evidence that engineering students’ undergone CPBL course will enhance their problem solving skills. However, the study has a few limitations:

Firstly, the research on enhancement problem solving skills is from students’ perspective. Unlike some problem solving studies, the designed assessment was developed not as a means to measure the ability of problem solving enhancement per se, although the overall pattern indicated from scores for deep learning in tests were analyzed. It is a self-evaluation instrument to see whether there are significant improvements in problem solving skills among engineering students who had undergone CPBL.

Secondly, since this is a benchmark analysis, the study is done only on one class, with an experienced CPBL practitioner. Evaluations are based on pre-post analysis in this class alone. It does not involve other CPBL practitioner or other group of students taking the same subject from different lecturers. Thirdly, the research does not propose any extra problem solving topology, nor does it introduce any additional problem solving inventories.

5.7 Recommendation for Future Works

The research has proven that the hybrid model of CL and PBL, named CPBL teaching methodology, has significantly enhanced engineering problem solving skills among engineering students. Based upon the teaching methodology, the research has define what it meant by problem solving skills and enhancement of problem solving skills. In also highlighted the processes involved that caused the enhancement. By doing so, the research has maintained it focused on students and the enhancement of students' problem solving skills through CPBL teaching methodology. Only little effort has been put on the instructional design perspectives, the support structures, and the deep thinking and meta-cognitive elements directly involved in the students while experiencing problem solving. Therefore, a few recommendations could be made for the continuation of the research work and as follows:

Firstly, the work can be expended to cover a wider spectrum of enhancing engineering problem solving skills by looking at the process involved in deep thinking and meta-cognitive elements of students going through CPBL. In doing so, the thinking process of selected students from various backgrounds and achievements should be closely studied and monitored.

Secondly, since CPBL is a challenge for the students compared to the traditional lecturer-centered learning, the research can be expended to rigorously study the motivational and students' support systems. As exposed in this research, motivation and learning strategies are crucial elements of problem solving skills. Therefore, the question is how to motivate students to overcome this challenge? What kind of support systems do the students require to successfully excel in a course that used CPBL as a means of learning, and at the same time minimizing supervision? How and to what extent should a lecturer assist the students in a CPBL class?

Thirdly, a study about how to best train the lecturers or facilitators is recommended. To successfully implement CPBL, lecturers need to undergo a series of trainings, mainly on active learning, CL, than followed by PBL. To jump-start from traditional learning straight to CPBL, without any proper training is very challenging. It might jeopardized not only the lecturers' intention to improve their teaching methodology, but more serious is the students' learning and commitments. Lecturers and students can be very frustrated if the CPBL failed to work properly. It is indeed important, as a continuation of this research, to study on how to successfully train the lecturers so that they are well equipped before fully implementing CPBL in their class. It is in fact the ultimate objective of the researcher to produce proper training guidelines for students, as well as lecturers on how to best implement CPBL in higher learning institutions.

Fourthly, there are three factors which directly contribute to the enhancement of problem skills among engineering students using CPBL which are the problem solving elements, the motivation and learning strategies, and the team working. Therefore, the study should further investigate the correlation and interrelation between all the three factors.

Finally, the research can be extended from the instructional design perspective. With respect to this, there are many questions that required answers. For example, are the problems given enough or too much? Are the problems too complex? Is the coursework load too much compared to the number of credit hours? What kind of scaffolding is required, and when and how to remove it? As a preliminary investigation, the researcher would like to propose the following promising practices. With regard to this, for the future research, this proposed promising practices need to be verified and validated. Last, but not least, can the practices be generalized to other courses?

5.7.1 The Promising Practice

Figure 5.13 is a proposed promising practice on enhancing problem solving skills among engineering students through CPBL. This promising practice is designed for a typical, three credit-hour engineering course, for a semester consisting of 14 to 15 weeks. The proposal is mainly based upon the practices used in CPBL methodology (Mohd-Yusof and Helmi, 2010), the practices used in McMaster

Problem Solving (MPS) workshops (Woods, 1997), and the developed model mentioned in previous section.

Unlike Woods' MPS "workshops", where the stages are distributed throughout the program, this promising practice developed students' problem solving skills within a course. Woods argued that developing problem solving skills when students are learning new subject knowledge is a challenge. Here, the practice applied Woods' problem solving program framework into a content-based course using CPBL to make the challenge more manageable. Apart from the three-stages embedded in the practice, another stage is added. This is the final stage where students will apply their knowledge learned throughout the course in solving one realistic industrial problem. The students will have to use their knowledge and gather their information from the industry to solve the problem. It is expected that after solving several problems through a series of problem solving and CPBL cycles, students will transform from novice engineering problem solvers to acquire traits of those approaching experts within the course duration. Undoubtedly, these skills can be further enhanced in an institutional or programme-wide approach. With the extent of enhancement in problem-solving skills in students shown within just a semester of CPBL, the potential in reinforcing and strengthening these skills within a systematic curriculum is definitely very high. Therefore, this research can be served as a basis and guide for engineering educators and engineering programme owners in making decisions in choosing a teaching and learning methodology and curricula approach, especially in attaining outcomes in problem solving. This is indeed significant, especially in engineering education, since concrete studies in the effectiveness of PBL in a typical course setting, particularly in developing problem-solving skills, was previously not available.

Considered as the most complex of all intellectual functions, problem solving has been defined as higher-order cognitive process that requires certain pedagogical ways to improve. Rooted in both constructivist and social constructivist approaches, CPBL is said to enhance the skills. The research has provided strong evidences to justify the claim. The result shows the effectiveness of CPBL in enhancing problem solving skills among engineering students, and how it actually helps the students in enhancing the skills. Bearing in mind the limitations to the study as stated above, this research revealed how problem solving skills were actually developed when students go through CPBL within a semester. This is immensely important for informing engineering educators on the important elements within CPBL in guiding students, especially those who face it for the first time. This is also significant in encouraging engineering educators who are new to implementing CPBL to understand the initial difficulties that students face and the immense progress that can be made with proper support.

This chapter concludes the research. It highlighted the motive of the study and the methodology that had been selected. Six conclusions were forwarded to show the successfulness of the research. The research proposed several ideas for future direction. Based on the result, it has put forth a preliminary work on designing instructional practices by proposing a promising practice for enhancing problem solving skills on engineering students through CPBL for future investigation, with the hope that all his findings will contribute to the body of knowledge for the advancement of future engineering education.

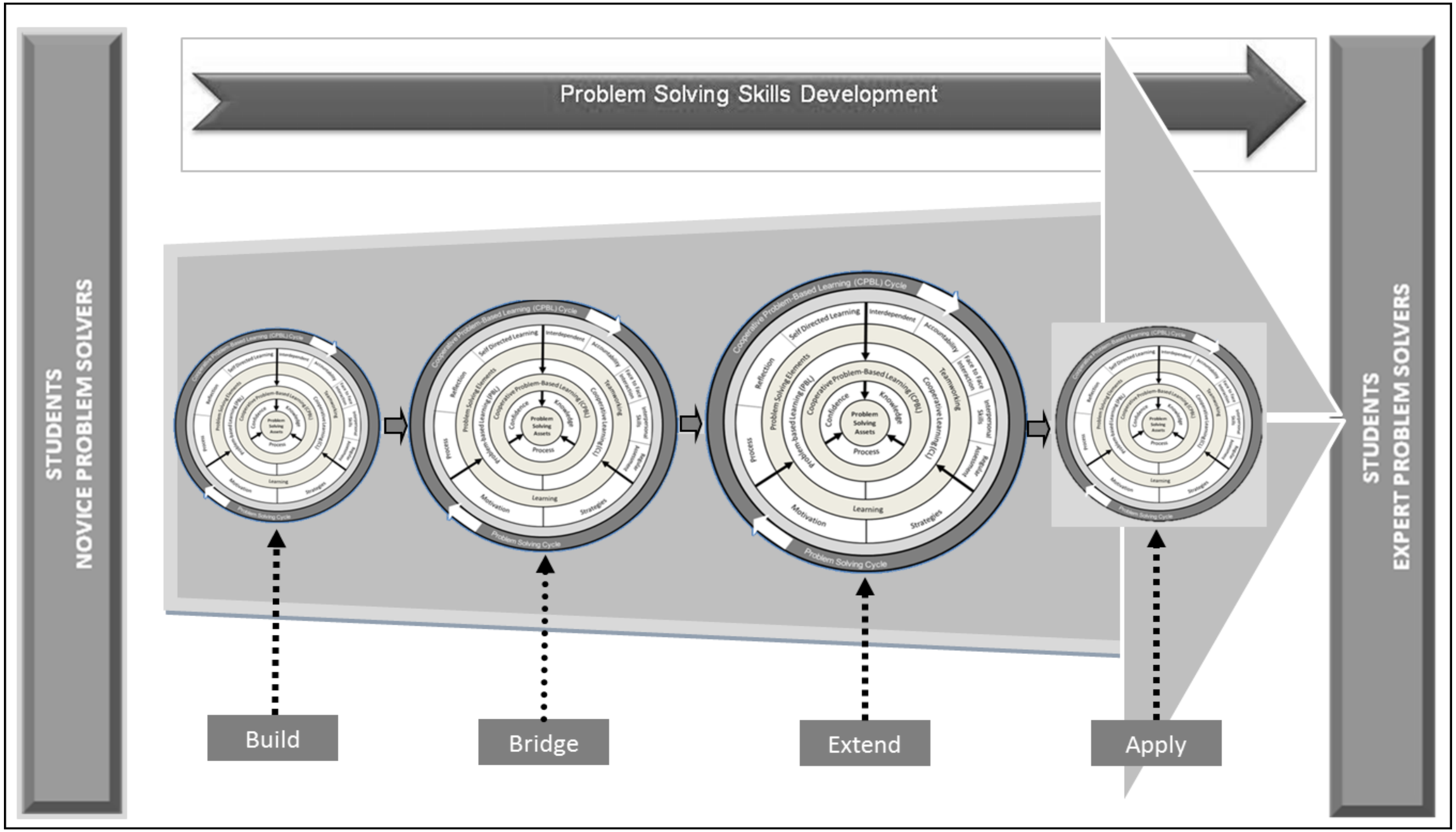

Figure 5.13: Promising practice for enhancing problem solving skills of engineering students through CPBL

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APPENDIX A

Table A: The Primary Themes of Workplace Problems

(Jonassen, Strobel and Lee, 2006)

Themes	Descriptions
1. Workplace problem are ill-structured	Initially some problems are well-structured, but as constraints and unanticipated problems became apparent (ex. working with people, dealing with environment, incomplete information), the problems became ill-structured.
2. Ill-structured problems include aggregate of well-structured problems	Within large projects, numerous well-structured problems are solved.
3. Ill-structured problems have multiple, often conflicting goals	In textbooks problems, the goal is obvious. But in workplace problem solving there are multiple sub-goal that must be considered. Sub-goal can often conflict with the primary goal, so engineers must determine which goals have higher priority, and often those goals have nothing to do with engineering outcomes.
4. Ill-structured problem are solve in many different ways	Use their professional judgment and rely on experience. The implication of this in engineering education is obvious. So, students must learn to identify and evaluate multiple solution methods instead of one single correct solution method.
5. Success are rarely measured by engineering standards	Although solutions to workplace problems must meet standards, but those are rarely the standards that are used to describe the success of a project. For most engineers, the most common criteria are to satisfy clients, completing project on time and staying under budget.
6. Most constraints are non-engineering	Most engineering program treat problems as engineering-only problems. However, workplace problems constraints had little to do with engineering – time, budget, cost, functionality, integration, politic, culture, etc.
7. Problem solving knowledge is distributed among team members	Traditional conceptual of learning have focused on knowledge that is acquired by individual. Newer perspective of learning is distributed among people. Knowledge exists not only in heads of learners, but also in the conversations and social relations among collaborators.
8. Most problems require extensive collaboration	Very few engineers engage in solitary problem solving. Majority of workplace problems, engineers must collaborate with variety of personnel in order to identify and solve the problems.
9. Engineers primarily rely on experiential knowledge	Research confirmed that experience is the most common determinant of expertise, and the recall of historical information is the most frequent strategy for solving problem.
10. Engineering problems often encounter unanticipated problems	Most everyday problems are dynamic; that is, the conditions change over time. Most of the problems the engineers talked about were large scale, in which a set of problems occurred. Some were unanticipated. Some were a combo of engineering and non-engineering.
11. Engineers use multiple forms of problem representation	Experts are able to represent problems in multiple ways, whereas novices are typically restricted to a single form of problem representations. Engineering students should not rely exclusively on formulas to represent problems. Research confirmed that a small minority of workplace engineers regularly use mathematical formulas to represent problems. Therefore, educators should also supplement students with alternative, qualitative problem representations.
12. Engineers recommend more communication skills in engineering curricula	Individuals may have mental representations derived from experience, but that knowledge is often useless unless it is shared. Engineers emphasized more instruction on client interaction, making oral presentations, and writing, as well as the ability to deal with complexity.

APPENDIX B

Problems Given to Students

CASE STUDY 1

HDA Process at Polystyrene (M) Sdn. Bhd.

The Scenario

Polystyrene (M) Sdn. Bhd., located in Pasir Gudang, is one of the largest producers of polystyrene in South-East Asia. In the company, polystyrene is produced from toluene, which is converted into benzene, ethylbenzene and styrene monomer through a series of complex processes. Finally, styrene monomer is polymerized to produce polystyrene.

Currently, Polystyrene (M) Sdn. Bhd. is offering a place for a team of undergraduates to attend their industrial training program. In order to recruit the best candidates, the company had taken part in the 2009 Career Fair which was held during the university semester break. For those interested, they were required to submit their resume. The selected students would be put in a team and called for a team-interview at the company later on. You and your teammates did not want to miss the chance. One day, you and your teammates received an offer letter from the company to attend an interview with regards to the industrial training program.

CASE STUDY 2: Part 1

HDA Process at Polystyrene (M) Sdn. Bhd.

The Scenario

You and your teammates are accepted to work as trainees at Polystyrene (M) Sdn. Bhd., Pasir Gudang. You have been assigned to learn about monitoring and operating the HDA Process. One Wednesday afternoon, you received a call from the Factory Manager, asking you and your teammates to meet him immediately. There is a task waiting…

"Good day guys. How're you doing?" said Mr. Iqbal as he took his seat.

"Great, thank you", said all of you, almost simultaneously.

"I've arranged a schedule on what you are going to do for the next 10 weeks you are here. Here, take a look…", said Mr. Iqbal as he handed over a detail schedule and a Gantt chart.

Then he said, "Now, let me brief you the overall picture of this task. Guys, currently in this company, product recovery and product quality is experimentally measured once in every four hours. So far, we don't have any special instrument to perform online measurement for such variables, and if any in the market, the instrument may perform measurement with substantial time delay. I strongly believe that you are very familiar with the terms offline and online measurement. In case of process operation runaway, time delay to identify the off-spec products will contribute to losses. Appropriate measures cannot be implemented immediately to bring the process back to normal and minimize the production of off-spec products as much as possible. As an alternative, instead of experimentally measured, product recovery and product quality can be predicted with a computer-aided system by developing a dynamic process model for the operational equipments, either using first principles (physical) or black-box approach."

"Ooo…", said all of you as you listen to Mr. Iqbal, followed with a deep breath.

Then Mr. Iqbal continued, "However, for your task, I want it to be first principles model so that we can gain enough insight on the actual operation of the process."
"But what exactly do we need to do?" asked one of you enthusiastically.

"Guys, we are talking about developing a dynamic process model as predictors to estimate the product recovery. I'd like you to derive the dynamic models of the flash drum so that we can predict the percent of product recovery from there. I'd recommend you to demonstrate the dynamic models of the flash drum in terms of plots so that it will be easier to observe the behaviour of its state variables. Be sure to state and justify all assumptions that you make in developing the models. Remember, any simplification on the models cannot be made without strong justification", explained Mr. Iqbal thoroughly.

"Ohhh…", said all of you as you listen to Mr. Iqbal carefully.

"Trust me, this is not that simple. So, I want to see a short progress report on the general process model first thing on Tuesday, 12th Jan. Please also make a list of data that you are needed to plot the models later on," reminded Mr. Iqbal.

"Is that all?" you asked as you jot down things that need to be done.

"Yup, I think that's all for now. I'll give you further instructions in our next meeting. If you need assistance, especially with regards to the process operation, you can easily contact me on-line through the company e-forum. Good luck!", told Mr. Iqbal.

CASE STUDY 2: Part 2

HDA Process at Polystyrene (M) Sdn. Bhd.

The Scenario

You and your teammates have been assigned to derive time-domain dynamic process models of the flash drum in the HDA Process. One Wednesday afternoon, in the meeting room, after presenting the models that you have developed to the factory manager, he was about to give you another assignment…

“Ok guys, I think you’ve managed to understand the operational behaviour of the flash drum. Besides, the dynamic models that you’ve developed look acceptable to me”, said Mr. Iqbal.

“Thanks Mr. Iqbal”, said all of you with a bright smile.

“No biggie… But remember, be sure to properly justify all the assumptions that you made. This part need to be improved further – refer to my posts in the company e-forum”, added Mr. Iqbal.

“OK, got it”, said one of you, responding to Mr. Iqbal.

Then he continued, “Now, I’ve new assignment for you guys. Since you’ve developed the dynamic models for the flash drum, why don’t we use them to understand its dynamic response? First of all, to make the analysis simpler, I want you transform the models into input-output models. Don’t forget to linearize the non-linear terms first. Then, make sure you determine the order of the models and calculate the steady-state gain and time constant of the models.”

“What do we need to do with those models?” you asked as you jotting down things that need to be done.

“I want you to check out how much the state variables deviate from their steady-state values if there is a change in the feed flow rate of the flash drum. Currently we’re facing ±10% fluctuation in the feed flow rate according to changes in production rate. I want you to demonstrate the response in terms of plots – please provide both positive and negative effects of the input variables towards the output variables,” explained Mr. Iqbal thoroughly.

“Emm what else…”, said Mr. Iqbal thoughtfully while everyone else is keep silent.
Then he continued again, “Ohhh please also suggest on what we can do to deal with such deviations. Please bear in mind that there is a controller installed in the system.

You may need to play around with the controller function in order to investigate this occurrence."

"That's all?" asked one of you enthusiastically, expecting more.

"Yeahhh, I guess. You can keep in touch with me through the company e-forum. I'll try my best to help you out. Please prepare a proper report on the complete dynamic models of the flash drum and all the things that I've asked you to do since the first part of this assignment. Submit your full report to me on Monday, January 25th. Wish you all the best and good luck!" told Mr. Iqbal as he was ready to leave the meeting room.

CASE STUDY 3: Part 1

HDA Process at Polystyrene (M) Sdn. Bhd.
The Scenario

You have just graduated from UTM. Because of your excellent results (especially in your Process Control and Dynamics course), excellent performance during industrial training and credentials, you are hired and assigned to work with a control engineering and troubleshooting team of Polystyrene (M) Sdn. Bhd.. Since you have just been hired and are still under probation, you are not allowed to take any leave for three months and thus only have four days break for the Chinese New Year holidays. Once Wednesday afternoon, while everybody was enthusiastically chatting on their preparation and planning for the Chinese New Year holidays, your mail box beeped, and you received the following message from the team leader:

CASE STUDY 3: Part 2

HDA Process at Polystyrene (M) Sdn. Bhd.

To: Control Eng. & Troubleshooting Team <control.team@psm.my>

From: Iqbal Ridha <iqbal.ridha@psm.my>

Date: 12/02/2010 04:00 PM

Attachments: drum_layout_ver2.jpg

Subject: step tests, stability analysis & tuning PID controllers

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Dear engineers,

Now that you have the general block diagram for level and temperature control loops, I want you to complete those diagrams with their respective transfer functions. I've contacted Mr. Zam and he agreed to come over on 25th Feb. He'll guide you on how to perform step tests and tuning PID controllers in hysys dynamics. Whenever you're doing step tests or tuning controllers, always bear in mind that the allowable limit for step change is within ±5% from the initial value.

Once you complete the block diagrams, I want you to perform stability analysis for both control loops – just use the general stability criterion and Routh stability criterion. I want to see the stability range for P-controller tuning parameter, Kc, for both control loops. This will be your tuning guideline to figure out the appropriate value of Kc and other tuning parameters.

I also want you to tune both controllers. Use off-line Cohen-Coon and on-line Ziegler-Nichols tuning methods for both servo and regulatory controls. Tune the controllers in hysys and simulink, then compare the results. Finally, suggest a feedback controller mode together with its parameter/s that is suitable to tackle each control variable. These will be our guideline when tuning process is carried out on the actual controllers. I expect fine tuning for both controllers simultaneously.

Enclosed - corrected P&ID for the HE and flash drum, brief description on each of the control loops plus instrumentation info, and essential data to calculate the transfer functions. I look forward to receiving your complete report on Wednesday, 3rd March.

Iqbal Ridha,
Leader, Control Eng. & Troubleshooting Team,
Polystyrene (M) Sdn. Bhd

FINAL CASE STUDY

Design of Automatic Control System for Merry Ingredients (M) Sdn Bhd

The Scenario

Now that you have experience as a process engineer, you have decided to join a process control consultancy firm, Custom Consulting Group (CCG) Sdn Bhd. You are hired because of your knowledge in chemical engineering, experience as a process engineer, and credentials. Since many of the firm's engineers are electrical and mechanical engineers, your job scope includes: i) understand, describe and analyze chemical processes, and ii) design and evaluate automatic control systems. One Thursday morning, you received the following email from the general manager:

To: Design Team <design.team@ccg.my>
From: Takahiro Matsuda <takahiro.matsuda@ccg.my>
Date: 11/03/2010 10:00AM
Subject: Design of automatic control system for Merry Ingredients (M) Sdn Bhd

Good day engineers,

Good news! Merry Ingredients (M) Sdn Bhd is now working on new projects, designing an automatic control system for their Wet-Mix Process and Wastewater Treatment Plant. They are urgently looking for the potential consultant/s to work on these projects. Due to our excellent track record in the previous consultancy projects, they've invited us to bid for these projects. Therefore, I'd like to send over two teams from our firm, propose the control strategies, to win both projects – one team will be handling one project each. However, this is only a preliminary design – you don't have to put so much detail on the instrumentation, budget, or any other particulars for design of automatic control systems.

As usual, you need to use the established techniques for determining and designing control systems. Please ensure that you use the accepted selection guidelines for the proper selection of variables. Use the control design form to make your work more systematic. You should be able to justify whatever that you want to do. Evaluate if you should include more advanced control systems, such as feedforward, cascade, ratio, split-range and others if there is a need to do so.

Enclosed are the process description and simplified PFD of the process plants – that's all we got from Merry. Anyway, they are willing to give you and your team a tour to the plant, at Tampoi, next week. But before you go, I want to see a detailed list of information that you need from Merry. Besides, I also want you to carry out a review on the related process so that you have a picture about the processes as well as the projects.

Guys, please do this well. You're selling our excellent reputation out there. Make sure you come up with a good proposal and win the projects. Don't screw up!

Regards,

Takahiro Matsuda – GM –

MERRY'S WET-MIX PROCESS

Process Description

Plant : Dryer 2, Merry Ingredients (M) Sdn Bhd, Johor Bahru

Plant Capacity : Maximum of 6 tons per batch

Merry Ingredients (M) Sdn Bhd, located in Johor Bahru is a spray dryer manufacturing facility, producing more than 100 types of dried powder products which are widely use in food and beverage industries worldwide. Some of the products manufactured in this facility are non-dairy creamers, clouding agents, emulsifier powders, whip toppings, cheese powders, nutritional products and others. There are two spray dryer plants available at Merry, named as Dryer 1 & Dryer 2, where those consist of both semi-batch and continuous processes throughout the production.

Semi-batch processes are located at more upstream in the production line for both dryers while continuous processes are located at more downstream. Upstream processes are mainly raw materials mixing, homogenizing, and pasteurizing. Raw materials are mixed and prepared in batches with various batch sizes, depending on product up-scaling recipe before going through homogenizing and pasteurizing process. From pasteurization until spray drying, the processes are more continuous before packing process in a dedicated packing room.

There are four tanks dedicated for wet mixing process in Dryer 2, which are oil melting tank, liquiverter, and two units of dissolvers. Oil melting tank and liquiverter are pre-mixture preparation tanks, whereas dissolvers are the final product mixing tank. Dryer 2 contains two sets of dissolvers due to batch sequencing, where product mixing and product drying occur at the same time, alternately between these two tanks.

Oil melting tank is used for oil pre-mixture preparation for product processing. Pre-heated oil around 60-70oC will be manually mixed with emulsifier in this tank before being transferred to dissolver for other ingredients mixing. Although the capacity for oil melting tank is 4MT, oil usage for every batch will depend on each product up-scaling recipe. Different products require a specific production recipe.

Liquiverter is designated for protein preparation, where protein is used as particle carriers for product drying. This 2MT capacity tank is used for manual preparation of Sodium Caseinate (protein) from the reaction of Acid Casein and Sodium Hydroxide at the temperature around 55-65oC. However, depending on global market stock, costing and customer requirement, prepared Sodium Caseinate may also be used, and therefore only manual dissolving of Sodium Caseinate is needed for protein preparation. Potassium Caseinate is also occasionally used as protein source due to customer requirement. Quantity of protein used is around 1.5-2.5% depending on product drying ability.

Each dissolver tanks in Dryer 1 & Dryer 2 has the same capacity of 8MT, usually operated around 55-65oC, depending on the operating condition of a specific product. The function of dissolver is for preparation of final product where all ingredients are mixed in this tank either manually or automatically transferred from oil melting tank and liquiverter. After completing the mixing process based on the procedures for each product recipe, an amount of slurry sample in dissolver will be taken and tested in lab to meet the product specification.

Complete batch of product mixture in respective dissolvers will be pumped through homogenizer for homogenization process in order to get equal product globules with similar ingredients distribution. There are two stages of homogenizing which operates until maximum total pressure of 200bar depending of product requirement before being buffered up in a dryer surge tank. This 1MT capacity surge tank is used as mixture buffering before pasteurizing and drying process with minimum operating level control of 50kg and maximum operating level around 700-800kg.

Product mixture is then pumped to Terlet continuously for pasteurization process with operating temperature around 80oC to eliminate all pathogen growth in the products. The pasteurization process is one of the Critical Control Point (CCP) in the processing line to ensure food safety in our products. The mixture will then pumped to the top level of spray dryer by high pressure pump with the maximum operating pressure of 300bar. The flow rate of product drying will be controlled by high pressure pump and varies based on product drying capability. The product will then be dried by hot air supplied into the spray drying chamber before being packed in a packing room with high-hygiene level and positive air environment. Finally product will be stored in the warehouse before being shipped out to customers.

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Enclosed are the process description and simplified PFD of the process plants – that's all we got from Merry. Anyway, they are willing to give you and your team a tour to the plant, at Tampoi, next week. But before you go, I want to see a detailed list of information that you need from Merry. Besides, I also want you to carry out a review on the related process so that you have a picture about the processes as well as the projects.

Guys, please do this well. You're selling our excellent reputation out there. Make sure you come up with a good proposal and win the projects. Don't screw up!

Regards,

Takahiro Matsuda – GM –

APPENDIX C

My Role is Questionnaire (MRIQ), (Woods, 1997)

The following 18 items are arranged with options (a and b or a, b and c). Each option represents a preference you may or may not hold. Rate your preferences for each item by giving a score from 0 to 5. “0” means you strongly disagree and strongly agree with the other option. “5” means you strongly agree and strongly disagree with the other option. The scores for a and b, or a, b and c MUST ADD UP to 5 (0 and 5, 1 and 4, 2 and 3. Etc..) Place your rating in the box ‘R’ next to the statement.

I think my role as a lecturer is….

Statement	R	Statement	R
1a. I have a basic conviction that I can make a difference		1b People come to me with basic attitudes and won't change	
2a. My role is to maintain high standards and fail those who do not make the standards.		2b. My role is to help each succeed and make the most of his/her abilities.	
3a. My role is to uncover material so that students understand.		3b. My role is to cover the material in the curriculum.	
4a. My role is to make learning fun.		4b. Learning is serious business. My role is to be well prepared.	
5a. My responsibility is to teach subjects.		5b. My responsibility is to teach people	
6a. Students must grow personally as well as intellectually		6b. The sole purpose of university is intellectual growth	
7a. Teaching, research, consulting are all opportunities to help others learn. The only difference is the client and the "class size". Teaching and research are a seamless continuum of learning.		7b. Teaching is the burden I must bear to allow me to do research	
		7c. Research is the burden I must bear to allow me to teach in university.	
8a. Teaching and learning are a two-way responsibility. If students fail it is partly my fault.		8b. Learning is one-way; I do my thing, and it's up to the students to learn.	
9a. If students understand my presentation, they will automatically remember the material. Learning is rote memorization and recall of facts.		9b. Understanding is not remembering. Students and I need opportunities to see new concepts in perspective to understand their limitations and to reach conclusions. Learning is active, independent and self-directed	
10a. Students should learn knowledge and the processes for working with that knowledge. Knowledge cannot be separated from thinking.		10b. All students need to learn in college is knowledge.	
11a. The development of values is an integral part of my instructional plan. Values play a significant role in my student's future success.		11b. The development of values is the responsibility of the home and/or the religious component of the student's life. You can't measure "value" development; therefore, it is inappropriate to include this area in one's goals.	
12 a. Students should self-assess. My role is to ensure that the assessment process used by the students is valid. I consider the goals, criteria and the quality of the evidence.		12b. Assessment of students is my responsibility. I create and mark all the exams that are used to measure the quality of student learning.	
13a. My role is to design the whole learning process. Students just have to follow my design.		13b. My role is to empower students with all elements in the learning process: goals, choice of text, assessment...	
l4a. I am a resource to help students learn; students have the principal responsibility for making and carrying out their own plans.		l4b. I am the source of knowledge. I have the advanced training to be shared with them.	
15a. My role is to help students with academic and intellectual issues. It's not my responsibility to get involved with their personal and social life.		15b. My role is to help students with academic and intellectual issues and to help them with personal problems	
		15c My role is to help students with academic and intellectual issues and to informally socialize and attend student events	
16a. I prepare the detailed learning objectives, the assessment criteria but publish general guidelines for the students; to do otherwise provides too much detail; it's overwhelming for the students.		16b. I publish detailed learning objectives and assessment criteria.	
		l6c. Students should prepare detailed learning objectives and assessment criteria. I monitor the process to ensure the standards are met.	
17a. My role is to help them solve problems similar to those they will encounter in professional practice.		l7b. My role is to ensure that they know the fundamentals. I use problems that help develop and test that understanding.	

APPENDIX D

Engineering Problem Solving Instrument Constructs

Table B(1) Problem Identification

	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/ 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.

Table B(2) Problem Analysis and Synthesis

	Statement	**Option 1**	**Option 2**
Knowledge	When analyzing a problem,	I will find suitable formulas and apply it to the problem based on examples from books	I will plan and evaluate several possible alternatives to solve the problem.
Belief/ Motivation/ Expectation	In generating solution to a problem,	I will straight away solve the problem and come to a conclusion	I use different perspectives and point of views before conclusion is made.
	Linking problems to principles of science and engineering	is so boring and tiring	is very interesting and challenging
Process	When analyzing a problem,	I am satisfied and accept ideas given by my peers, especially from the smart and most convincing student.	I will discuss and debate ideas with my peers
	Most steps and conclusions taken in analyzing problem	are based on guts feeling and intuitive	are based on facts and understanding
	When I am stuck while analyzing a problem	I will avoid thinking about the matter. I will proceed to generate the solution even though I realize there will be flaws in my result	I took it as a challenge. I will think deeply about it, and calmly try several other approaches until I am satisfied with the analyses

Table B(3) Solution Generation

	Statement	**Option 1**	**Option 2**
Knowledge	When generating solution to a problem	I am satisfied with conclusion proposed by my friends.	I discuss with my peers based on concepts that I understood for evaluation and justification
Belief/ Motivation/ Expectation	In generating solution,	I do not have to recheck the result for several times. It is important for me to get to the conclusion as soon as possible.	I will ensure the result fulfill all the solution criteria before any conclusion is made.
Process	When solution is generated for the first time,	I always satisfy with it and draw a conclusion.	I compare the solution with several other alternatives/ approach, and draw a conclusion based on the solution criteria.
	In generating solution, I spent most of my time	calculating answers to the solution	Planning and discussing different perspectives to get the best solution.
	If I cannot generate solution to a problem after analyzing and synthesizing for a certain period of time	I will not waste too much time dwelling with it. I will just put down some kind of answer, even though I know the answer is not satisfactory	I will not give up. I will keep on thinking and searching for the answer, until I am satisfied

Table B(4) Reflection

	Statement	**Option 1**	**Option 2**
Knowledge	When a problem is solved,	I find it difficult to generalize the problem for different contexts.	I can think of how to generalize the concepts of the problem for different contexts.
Belief/ Motivation/ Expectation	In the process of solving problem,	I am very cautious with time and effort that I have to spend. Rethinking and analyzing whatever that had been discussed is a waste of time.	I am very concerned with accuracy. I will rethink back whatever decision that had been made to ensure the generated result is correct and fulfill all solution criteria.
Process	When successfully solving a problem,	I feel satisfied with the result, and prefer to forget the difficulties faced while solving the problem.	I will reflect on the way the problem was solved. This is for the purpose of improving problem solving strategy, thus increasing problem solving skills

Table B(5) Self-directed Learning

	Statement	Option 1	Option 2
Knowledge	When solving a problem,	I read little, but prefer to listen to the explanations given by peers or lecturer.	I will think of what I know, and what I need to know, and fill the gaps through various resources. I will discuss with my peers for brainstorming and identifying difficult concepts for further clarification from discussion with the whole class.
Belief/ Motivation/ Expectation	Solving problem in group	will slow down my process of learning. I have to follow the pace of the slowest peer in my group.	will increase my understanding of knowledge of the problem. This is because I will learn with a view of sharing.
	When a new concept is introduced,	I feel uneasy and confused	I can accept difficulties when facing and trying to learn it.
Process	While gathering information required to solve problem,	I used text book and reference suggested by the lecturer.	apart from text book and references suggested by the lecturer, I also use internet, journals, other related books, and experts opinion

APPENDIX E

Engineering Problem Solving Instrument (EPSI)

Problem Solving Questionnaire

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 in class	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.

	STATEMENT	Option 1	R_1	Option 2	R_2
1.	When analyzing a problem,	I will plan and evaluate several possible alternatives to solve the problem.		I will find suitable formulas and apply it to the problem based on examples from books.	
2.	When attempting to solve a new problem,	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.	
3.	Solving problem in group,	will slow down my process of learning. I have to follow the pace of the slowest peer in my group.		will increase my understanding of knowledge of the problem. This is because I will learn with a view of sharing.	
4.	Linking problems to principles of science and engineering,	is very interesting and challenging.		is so boring and tiring.	
5.	In generating solution to a problem,	I will straight away solve the problem and come to a conclusion.		I use different perspectives and point of views before conclusion is mad	
6.	Given a choice,	I prefer challenging problems.		I will avoid challenging problems.	
7.	When I am stuck while analyzing a problem,	I took it as a challenge. I will think deeply about it, and calmly try several other approaches until I am satisfied with the analyses.		I will avoid thinking about the matter. I will proceed to generate the solution even though I realize there will be flaws in my result.	
8.	While gathering information required to solve problem,	apart from text book and references suggested by the lecturer, I also use internet, journals, other related books, and experts opinion.		I used text book and reference suggested by the lecturer.	
9.	When solving a problem,	I read little, but prefer to listen to the explanations given by peers or lecturer.		I will think of what I know, and what I need to know, and fill the gaps through various resources. I will discuss with my peers for brainstorming and identifying difficult concepts for further clarification from discussion with the whole class.	

10.	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.	
11.	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.	
12.	When a problem is solved,	I find it difficult to generalize the problem for different contexts.		I can think of how to generalize the concepts of the problem for different contexts.	
13.	When a new concept is introduced,	I can accept difficulties when facing and trying to learn it.		I feel uneasy and confused.	
14.	When successfully solving a problem,	I feel satisfied with the result, and prefer to forget the difficulties faced while solving the problem.		I will reflect on the way the problem was solved. This is for the purpose of improving problem solving strategy, thus increasing problem solving skills.	
15.	When attempting to solve a new problem,	I will try to understand the problem by redefining it using my own words.		I will seek help from my friends to explain the meaning of the problem.	
16.	In generating solution,	I will ensure the result fulfill all the solution criteria before any conclusion is made.		I do not have to recheck the result for several times. It is important for me to get to the conclusion as soon as possible.	
17.	In the process of solving problem,	I am very cautious with time and effort that I have to spend. Rethinking and analyzing whatever that had been discussed is a waste of time.		I am very concerned with accuracy. I will rethink back whatever decision that had been made to ensure the generated result is correct and fulfill all solution criteria.	
18.	When generating solution to a problem,	I discuss with my peers based on concepts that I understood for evaluation and justification.		I am satisfied with conclusion proposed by my friends.	
19.	When analyzing a problem,	I am satisfied and accept ideas given by my peers, especially from the smart and most convincing student.		I will discuss and debate ideas with my peers.	

20.	If I cannot generate solution to a problem after analyzing and synthesizing for a certain period of time,	I will not give up. I will keep on thinking and searching for the answer, until I am satisfied.		I will not waste too much time dwelling with it. I will just put down some kind of answer, even though I know the answer is not satisfactory.	
21.	When solution is generated for the first time,	I always satisfy with it and draw a conclusion.		I compare the solution with several other alternatives/ approach, and draw a conclusion based on the solution criteria.	
22.	In generating solution, I spent most of my time,	Planning and discussing different perspectives to get the best solution.		calculating answers to the solution.	
23.	I faced a new problem,	with interest to develop myself.		because of marks for my grade.	
24.	Most steps and conclusions taken in analyzing problem,	are based on guts feeling and intuitive.		are based on facts and understanding.	

APPENDIX F

Reliability Analysis – EPSI

No of Sample - 150

Reliability Statistics - Problem Identification

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.734	.734	6

Reliability Statistics – Analysis and Synthesis

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.805	.806	6

Reliability Statistics – Solution Generation

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.814	.819	5

Reliability Statistics - Reflection

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.727	.728	3

Reliability Statistics – Self Directed Learning

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.786	.793	3

Reliability Statistics – Knowledge

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.820	.827	5

Reliability Statistics – Expectation

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.844	.845	8

Reliability Statistics - Process

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.883	.884	11

Reliability Statistics – ALL

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.945	.946	24

APPENDIX G

Sample of Expert Validation

1. Problem Identification (PI)

	Agree	Disagree	Comment
Confuse: "After that, she gave us case study about control shower system. When I read the problem, I cannot think what exactly the problem wants."	✓		Could be "unclear" or "uncertain".
Problem Restatement: "As for my problem solving skills, there are slight improvements. The time requires getting to the problem statement gets shorter. This indicates that I know what my problem is and where I should head and what I should do."	✓		
Representation: "First of all, I try to understand all the knowledge which is new for me and made it into a mind map. For convenient and simple, it was an easier way to explain to my teammates."	✓		
Learning Issues: "Our first meeting was on the learning issues that we have discussed in the class. In order to have an effective meeting what we did was to read on all the learning issues and just focus more on one particular topic."	✓		
Team Peer Teaching: "Discussions in a team really help me a lot where we can teach them and learn with them. It actually gives me a long duration for me to remember what I have learn because before this, after I learned by my own and do not discuss to anyone, by a week, I couldn't remember what I've just learned before."	✓		
KNL Table: "Most important..i think is..knl table.."	✓		
Overall Class Discussion on PI: "The second class discussion was amazing. It was like the explosion of confusion + knowledge + "new" theory + a lot of assumption = more confusion."	✓		
Handling PI Problem: "In our first discussion, the truth is, all of my teammates are blurry including me. We actually don't know how to start this case study. So, all of us together had read again the handout of case study. We wrote it down one by one what we are supposed to do in this case study 3. Finally, we are clearer what we have to do after jotting things down in a piece of paper."	✓		
Reflection on PI: "The first step to start to solve a problem is usually the most difficult step. CPBL is just like a learning process that helps me to have courage and know how to step out the first step."	✓		

	Agree	Disagree	Comment
Self-Directed Learning on PI: "As for the feedback controller modes, at first, I was totally 'blur' when my teammates explained about the controller modes during peer teaching. They were total new things to me, and they looked very difficult to be understood. However, I decided to spend some time to understand more about the controller modes. Then, after more readings, I found myself having better understanding."	✓		

2. Problem Analysis and Synthesis (A&S)

	Agree	Disagree	Comment
Problem Analysis: "We analyze each of the graphs and try to get the data needed."	✓		
Problem Synthesis: "Now I know how to integrate.."	✓		
Evaluation: "For the first meeting, I showed my lists to Ho and Ching to ensure our work go smoothly. But, not all what we planned will go as we want. We still stuck with some problems in the progress. As my observation, we took much time just to complete the block diagram. That's why systematic work also needed in technical work."	✓		
Reflection on A&S: "Before, I just see the problem and solve it. But now I can provide more alternative to it."	✓		
SDL on A&S: "Through this case study I think it helps me to develop life-long or independent learning skills as well as to be critical thinker. Not all the information from book and internet is correct. Therefore, I need to know which is correct and applicable."	✓		
Handling A&S Problem: "But if looked back on what they did, I guess that their meeting was ineffective. This makes me to go into the problem and always view the problem at different angle so that our team will not face the similar problem and always ask when there is question."	✓		
Surface Understanding: "…XXXXX…"	✓		
Deep Understanding: "I always explore my thinking out of the boundary."	✓		

3. Solution Generation (SG)

	Agree	Disagree	Comment
Overall class discussion: “I love to have those kind of participation that given by other group because when we discuss we can see many different things and even “new” theories coming out. It is funny but as well effective.”	✓		
Report and Present: “After some correction by everyone on the solution, Mr A started to complete the simulation. Then, me and Ms B started to complete the report. Undeniable, I never worked with someone like Ms B. I can say that we have good chemistry. I started to do one part and she do another part and it continued until the report slightly finished. Then, we discussed on the response of the model. Everyone gave opinion and suggestion freely and finished within 1 hour. After typing on the discussion and editing, we completed the report successfully at 4a.m.”	✓		
Relection on SG: “The tedious part is sometimes, it really hard to reach to one final answer because all have different views on the topic that we discuss. At the end of CS1, I felt that our group can do better than that.”	✓		
Self Directed Learning on SG: “Before attend discussion, I already finish the report based on my understanding. I really think it was a simple task. So, I thought our meeting will finished by 2 hours. On the discussion, I propose my solution.”	✓		
Surface Understanding: “….XXXX…..”	✓		
Deep Understanding: “But the most interesting part is when completing final phase. That is the time where I can connect all the knowledge to one small design. I know where to begin and what to do.”	✓		

4. Self-Directed Learning on PSP

Self Directed Learning	Agree	Disagree	Comment
“On my learning process, it proves that I can be independent to get new knowledge. It is only the matters to get the confidence within myself and the place to seek for verification of the idea that passes my mind. For that, what I did in the class was to ask question in the overall class discussion.”	✓		

5. Reflection on PSP

	Agree	Disagree	Comment
Negative Aspects "At the beginning it is rather difficult because we don't know anything at all."	✓		
Positive Aspects "Before this I just read and then I don't know where to integrate and then, how to integrate. Now I know how to integrate, rather than just study."	✓		

Problem Solving Assets

1. Knowledge

	Agree	Disagree	Comment
Retention: "Discussions in a team really help me a lot where we can teach them and learn with them. It actually gives me a long duration for me to remember what have I learn because before this, after I learn by my own and do not discuss to anyone, by a week, I couldn't remember what I've just learn before."	✓		
Facts: "Well, first time is always the most difficult. The more we practice, easier it gets."	✓		
Strategic: "When my teammates voice out their views, I will listen and try to think of some solutions or better ideas that might be helpful."	✓		
Procedural: "During class, new method of learning is used. At first, it was difficult. Well, I'm not usually prepared before going to any class. But this class required us to learn ourselves. I'm not that good learning individually. But the approach was different. Learning issues are divided among team members, than we have to teach one another. I start taking it seriously because if our teammate fails to understand the topic, it means I fail. We have the responsibility to make sure our teammate understand it properly."	✓		Also an evidence of self-directed learning.
Concepts: "Just imagine how it would be if we were just given normal lectures as I would have preferred. All these interesting 'conflicts' would not have happened. But, would I learn anything from the lectures?? Well, most probably the answer would be a "no". Perhaps, I would know the definitions of the terms very well, and be able to differentiate between 'controlled variables' and 'manipulated variables'. But when given the case study, I would certainly got stuck and had difficulties solving them."	✓		
Understanding: "I would read on my own and then discuss among team mates to see that there is any misunderstanding and verification. If the verification can't be obtained than we will try to get it from the overall discussion."	✓		

2. Confidence

	Agree	Disagree	Comment
Expectation: "I might say that I am scare or busy but somehow I still produce what other produce and I hope that I produce a better result than others."	✓		
Belief: "At the end of case study 1, I felt that our group can do better than that."	✓		
Motivation: "At the beginning of the semester, I was quite a passive person during discussions. Luckily, I have supportive teammates who always encouraged me and tend to ask me questions so that I would speak more. Then, I started to be more active to voice out my opinions."	✓		

3. Process

	Agree	Disagree	Comment
Questioning: "Asking for verification sometimes need a lot of reading and if I don't read a lot then I don't know where to ask and what to ask."	✓		
Discussing: "Talking about the content, we have covered the topic of control configurations and variables in a different way. I would read on my own and then discuss among team mates to see that there is any misunderstanding and verification. If the verification can't be obtained than we will try to get it from the overall discussion."	✓		
Explaining: "When we are discussing about certain topics, we help each other to understand the topic better."	✓		
Planning: "Then, our first case study came out. I cannot managed my time because of too many things to do. To prevent the time management problem, I included our discussion in the time table. I fixed the time. So that, I will prepared well before attend the meeting and class."	✓		
Analyzing: " It makes me realize that study does not mean only reading but also finding ways to apply."	✓		
Executing: "Last time it is just one answer. Now it is different. It needs a lot of answer. But it is up to us to choose which one is the best."	✓		Could also be "decision making"?
Reading: "Before team meeting, I goggling the related learning issues around internet and reference books."	✓		googling" Could also be "researching"?
Representing: "As we know, in designing a model, we cannot have too complicated model and too simplified model."	✓		

APPENDIX H

Motivation and Learning Strategies Questionnaire (Pintrich, 1990)

Motivation Learning and Strategies Questionnaire

Please complete all the questionnaires truthfully. For each of the following question, please **write a number** (in the box) that corresponds with your experience that you gained while you are going through PBL class.
Rate yourself on a scale of 1 to 7.

Not at all true of me 1 2 3 4 5 6 7 Very true of me

1.	In a class like this, I prefer course material that really challenges me so I can learn new things.	☐
2.	Getting a good grade in this class is the most satisfying thing for me right now.	☐
3.	I think I will be able to use what I learn in this course in other courses.	☐
4.	If I study in appropriate ways, then I will be able to learn the material in this course.	☐
5.	When I study the readings for this course, I outline the material to help me organize my thoughts.	☐
6.	I often find myself questioning things I hear or read in this course to decide if I find them convincing.	☐
7.	I often feel so lazy or bored when I study for this class that I quit before I finish what I planned to do.	☐
8.	Even if I have trouble learning the material in this class, I try to do the work on my own, without help from anyone.	☐
9.	When studying for this course, I often try to explain the material to a classmate or a friend.	☐
10.	In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn.	☐
11.	The most important thing for me right now is improving my overall grade point average, so my main concern in this class is getting a good grade.	☐
12.	It is important for me to learn the course material in this class.	☐
13.	It is my own fault if I don’t learn the material in this course.	☐
14.	When I study for this course, I go through the readings and my class notes and try to find the most important ideas.	☐

15.	When a theory, interpretation, or conclusion is presented in class or in the readings, I try to decide if there is good supporting evidence.	☐
16.	I work hard to do well in this class even I don't like what we are doing.	☐
17.	I ask the instructor to clarify concepts I don't understand well.	☐
18.	I try to work with other students from this class to complete the course assignments.	☐
19.	The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible.	☐
20.	If I can, I want to get better grades in this class than most of the other students.	☐
21.	I am very interested in the content area of this course.	☐
22.	If I try hard enough, then I will understand the course material.	☐
23.	I make simple charts, diagrams, or tables to help me organize course material.	☐
24.	I treat the course material as a starting point and try to develop my own ideas about it.	☐
25.	When course work is difficult, I give up or only study the easy parts.	☐
26.	When I can't understand the material in this course, I ask another student in this class for help.	☐
27.	When studying for this course, I often set aside time to discuss the course material with a group of students from the class.	☐
28.	When I have the opportunity in this class, I choose course assignments that I can learn from even if they don't guarantee a good grade.	☐
29.	I want to do well in this class because it is important to show my ability to my family, friends, employer or others.	☐
30.	I think the course material in this class is useful for me to learn.	☐
31.	If I don't understand the course material, it is because I didn't try hard enough.	☐
32.	When I study for this course, I go over my class notes and make an outline of important concepts.	☐
33.	I try to play around with ideas of my own related to what I am learning in this course.	☐
34.	Even when course materials are dull and uninteresting, I manage to keep working until I finish.	☐
35.	I try to identify students in this class whom I can ask for help if necessary.	☐

36.	I like the subject matter of this course.	☐
37.	Whenever I read or hear an assertion or conclusion in this class, I think about possible alternatives.	☐
38.	Understanding the subject matter of this course is very important to me.	☐

APPENDIX I

Team Working Effectiveness Scores (Imbrie et al., 2005)

Team Working Effectiveness Scores

Please rate the following items based on how you and your team perceived on teamwork and team building. Your rating should be on a 5-point scale where **1= not at all** to **5=very true**

Not at all true of me — 1 — 2 — 3 — 4 — 5 — Very true of me

1.	My team collaborated effectively to complete our assignments.	☐
2.	My contributions to the team were appreciated by each team member.	☐
3.	My teammates displayed appropriate interpersonal skills when conflict arose.	☐
4.	I had confidence in each team member to contribute his/her fair share of what was required.	☐
5.	My team used a process /method (e.g., code of cooperation) to hold each member accountable	☐
6.	Team members were prepared for team meetings.	☐
7.	Team members arrived on time to team meetings.	☐
8.	At any particular time, I knew what each member of my team's role was so I knew what to expect from them.	☐
9.	An outside observer would have concluded our team had an effective process to complete our assignments.	☐
10.	The solutions of my team to course assignments were better than what I would have done on my own.	☐
11.	This team helped me understand the material presented in this course.	☐
12.	Working on this team made me realize some things about myself (e.g., communication ability, leadership) that I was not aware of.	☐

13.	This team enabled me to acquire the skills necessary to contribute to working on future teams	☐
14.	This team enhanced my academic learning.	☐
15.	My team was confident in its ability to overcome adversity (e.g., interpersonal conflict, assignments).	☐
16.	I feel a sense of accomplishment in my team's ability to work together.	☐
17.	This team gave me confidence in the ability of teamwork to solve problems.	☐
18.	My team had the collective abilities (e.g., communication, interpersonal, technical) to accomplish course assignments.	☐
19.	I was confident that our team produced acceptable solutions to course assignments.	☐
20.	This team helped me accomplish my individual goals for this course.	☐
21.	My team used clear, long term goals to complete tasks.	☐
22.	My team reflected upon its goals in order to plan for future work.	☐
23.	My team made use of incremental goals (i.e., we set short-term goals) in order to complete course assignments on time.	☐
24.	My input was used to set our team goals.	☐
25.	Overall, I thought being on this team was a very negative experience.	☐
26.	Our team did not function well as a team; we did not establish any process to hold one another accountable nor did I ever know what individuals were responsible for.	☐

APPENDIX J

Interview Questions

1. Do you know the difference between "problem solving" and "exercise solving"? *Can you elaborate*?
2. How do you find studying using PBL? *Can you explain your experience?*
3. At what stage of PBL do you think the most important? *Why*?
4. Do you prefer to solve a problem alone or in a group?
5. How do you find solving problems in a group?
6. Can you explain the process that you went through in solving a problem?
7. Can you explain the way you solve a problem, from problem definition, problem synthesis and analysis, and solution generation:
   (1) before attending this course,
   (2) during the 2^{nd} case study,
   (3) during the final case study.
8. Have you ever face with a conflict? *How do you deal with it*?
9. Have you ever get stuck along the way in solving a problem, how do you deal with it? How does your group deal with it? *Usually, at what stage in PS did you get stuck?*
10. How does this course prepare your as a learner?
11. How is your readiness to face the challenge in the working environment?
12. How much this course enhanced your PS skills? *Why*?
13. If I were to rate your PS skills from 1 (the worst) to 10 (the best), where would it be?
14. What is your opinion on how the course is designed? i.e. with 4 case studies, etc.
15. What is your advice to lecturers who would like to teach course using this CPBL methodology?
16. What are other subjects taken in this semester that might also enhance your problem solving skills?

APPENDIX K

Sample of Student's Reflection

We already reach the end of this semester. It had been a great semester where a lot of things happen. The semester starts with like any other semester but just the fact this semester we have control's class. Is it that bad? Naaa..it's not that bad. Actually it is quite fun. Huhu…I missed it already. How can I describe the feeling? The excitement was like attending a camp but it was for one semester and the moment we already closed with each other, it reached the end.

At the beginning, each team member was awkward. I learned that people are different with one and another. Maybe some issues we had the same understanding and thought, but there will always someone different. How to overcome it? Rather than ignoring that person, I learned to hear their thought, discuss with them and try to absorb their thought. We will never know what others are thinking. So, the best answer is to ask. There must be two way communications so that the discussion is effective.

During class, new method of learning is used. At first, it was difficult. Well, I'm not usually prepared before going to any class. But this class required us to learn ourselves. I'm not that good learning individually. But the approach was different. Learning issues are divided among team members, than we have to teach one another. I start taking it seriously because if our teammate fails to understand the topic, it means I fail. We have the responsibility to make sure our teammate understand it properly.

Within the 4 case study I have done together, the second one was the most challenging among all. Now that I think about it, it was not because it was difficult but because lack of communication. The first case study was easy (although that time it was difficult..). Not a lot of work, just a simple report. In CS2, modeling using first principle was started to be difficult. In my team, we didn't act according to the role. Even sometimes we forgot who the leader was. Maybe because of that the role kept overlapping. It will actually be better if we work according to the role. Each role has their responsibility.

There is one hidden part in myself that others found about me. During the peer rating comments, I realized that I am quite bossy. From before, I know that I prefer to divide task among team members but I didn't realized my ways of doing it is quite bossy. I still remember Lau said in my peer rating comments. "Ms YYY is like a lady boss". Haha…now I realized I am that scary to others sometimes. Maybe the way I approach people is quite straight forward and bold. I hope in the future I could change that part of me slowly. Other than that, I start to believe other people work. If before, I had the tendency to do all by myself but for control, it was impossible. So, I have to give my trust to other in order to finish the task.

However, after all the hard work with my teammate, I have to say, "It's been an honor working with you all". If I have the chance to go over again the same process, difficulties and hard work, I will not choose other people as my teammate. That's all for this semester…thank you for the great experience!!!

APPENDIX L

Test for Normality

Table F(1)Problem Solving Elements

		Problem Identification	Analysis and Synthesis	Solution Generation	Reflection	Self-directed Learning
Beginning of Semester	Skewness	.255	.412	.177	.155	-.104
	Std. Error of Skewness	.427	.427	.427	.427	.427
	Kurtosis	-.089	.575	-.623	-.259	-.334
	Std. Error of Kurtosis	.833	.833	.833	.833	.833
	Skewness Ratio	.600	.965	.415	.363	-.244
	Kurtosis Ratio	-.107	.690	-.748	-311	.401
End of Semester	Skewness	-.252	.162	-.163	-.262	.354
	Std. Error of Skewness	.427	.427	.427	.427	.427
	Kurtosis	.567	-.793	-1.122	-.556	-.501
	Std. Error of Kurtosis	.833	.833	.833	.833	.833
	Skewness Ratio	-.590	.380	-.382	-.614	.830
	Kurtosis Ratio	.681	-.952	-1.345	.667	.601

Table F(2) Team Working Effectiveness

		Interdependent	Potency	Goal Setting
Beginning of Semester	Skewness	-.558	-.359	-.522
	Std. Error of Skewness	.427	.427	.427
	Kurtosis	-.549	-.402	.947
	Std. Error of Kurtosis	.833	.833	.833
	Skewness Ratio	-1.307	-.841	1.222
	Kurtosis Ratio	0.660	.483	1.137
End of Semester	Skewness	-.678	-1.363	-.574
	Std. Error of Skewness	.427	.427	.427
	Kurtosis	.187	2.059	.274
	Std. Error of Kurtosis	.833	.833	.833
	Skewness Ratio	-1.588	-3.192	-1.344
	Kurtosis Ratio	.224	2.472	.329

Table F(3) Motivation and Learning Strategies

		Intrinsic	Extrinsic	Task Value	Belief	Orgn	Critical Thinking	Effort	Help Seeking
Beginning of Semester	Skewness	-.292	-.562	-.616	.092	-.089	-.279	-.253	.429
	Std. Error of Skewness	.427	.427	.427	.427	.427	.427	.427	.427
	Kurtosis	-1.029	.008	-.160	-.733	-.622	-.827	.487	.110
	Std. Error of Kurtosis	.833	.833	.833	.833	.833	.833	.833	.833
	Skewness Ratio	-.684	-1.316	-1.443	.215	-.208	-.653	-.593	1.005
	Kurtosis Ratio	-1.235	.010	-.192	-.880	-.747	-.993	.585	.132
End of Semester	Skewness	-.627	-.269	-.538	-.214	-.687	.360	.034	-.600
	Std. Error of Skewness	.427	.427	.427	.427	.427	.427	.427	.427
	Kurtosis	.759	-.478	.127	-.276	-.030	-.417	-.890	1.411
	Std. Error of Kurtosis	.833	.833	.833	.833	.833	.833	.833	.833
	Skewness Ratio	-1.468	-.630	-1.260	-.501	-1.61	.843	.080	-1.405
	Kurtosis Ratio	.911	-.574	.152	-.331	-.036	-.501	-1.07	1.694

Table F(4) Problem Solving Assets

		Knowledge	Expectation	Process
Beginning of Semester	Skewness	-.566	-.078	.331
	Std. Error of Skewness	.427	.427	.427
	Kurtosis	-.235	-.028	-.188
	Std. Error of Kurtosis	.833	.833	.833
	Skewness Ratio	-1.326	.183	0.775
	Kurtosis Ratio	-.232	-.034	-.226
End of Semester	Skewness	.028	.264	.068
	Std. Error of Skewness	.427	.427	.427
	Kurtosis	-.933	-.025	-.234
	Std. Error of Kurtosis	.833	.833	.833
	Skewness Ratio	.066	.618	.159
	Kurtosis Ratio	-1.120	-.030	-.281

APPENDIX M

List of Paper Published

1. Cooperative Problem-Based Learning (CPBL): A Practical PBL Model for a Typical Course (2011), *International Journal: Emerging Technologies in Learning*, iJET - Volume 6, Issues 3, September.

2. Designing Effective Learning Environment for Cooperative Problem-based Learning (CPBL) for Engineering Courses, (2008). ASEE Global Colloquium Proceedings, Cape Town, South Africa, Octobe.r.

3. Cooperative Problem-Based Learning (CPBL): Framework for Integrating Problem-Based Learning and Cooperative Learning, (2010). The 3rd Regional Conference on Engineering Education and Research in Higher Education (RCEE & RHEd2010), Kuching, Sarawak, 7-9th June.

4. Scaffolding students learning through Cooperative Problem-Based Learning (CPBL) Framework, (2010). Proceeding for the 9th ASEE Global Colloquium on Engineering Education, Singapore, Oct 18-21.

5. Motivation and Engagement of Learning in the Cooperative Problem-Based Learning (CPBL) Framework, (2011). Proceedings for the 2011 ASEE Annual Conference and Exposition on Engineering Education, Vancouver, Canada, June 26-30.

6. Cooperative Problem-based Learning: A Practical Model for Engineering Courses, (2011). Proceeding for the 2011 IEEE Educon, Amman, Jordan, 4-6 April. (IEEE Explorer)

7. Crafting Engineering Problems for Problem-Based Learning Curriculum, (2010) Proceeding for the 3rd Regional Conference on Engineering Education and Research in Higher Education (RCEE & RHEd2010), Kuching, Sarawak, 7-9th June.

8. Motivation in Problem-Based Learning Implementation, (2010). Proceeding for the 3rd Regional Conference on Engineering Education and Research in Higher Education (RCEE & RHEd2010), Kuching, Sarawak, 7-9th June.

9. Comparison of Problem-based Learning (PBL) Models in Higher Learning (2009). 2nd International PBL Symposium, Republic Polytechnic, Singapore, 10-12 June.

10. Effect of Facilitation on Outcomes and Students' Perception in Problem-based Learning (2009). Proceeding for 2nd International PBL Symposium, Singapore, 10-12 June.

11. Motivation and Engagement of Learning in the Cooperative Problem-Based Learning (CPBL) Framework (2011). Proceedings for the 2011 ASEE Annual Conference and Exposition on Engineering Education, Vancouver, Canada, June 26-30, 2011

12. An Instrument to Assess Students' Engineering Problem Solving Ability in Cooperative Problem-based Learning (2011), Proceedings for the 2011 ASEE Annual Conference and Exposition on Engineering Education, Vancouver, Canada, June 26-30.

13. Methods to Study Enhancement of Problem Solving Skills in Engineering Students through Cooperative Problem-Based Learning (2010). Proceeding for the 3rd Regional Conference on Engineering Education and Research in Higher Education (RCEE & RHEd2010), Kuching, Sarawak, 7-9th June 2010.