PROBLEM SOLVING PROCESS RUBRICS FOR PROJECT-BASED LEARNING IN ELECTRICAL LABORATORY

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In the name of Allah, the Most Beneficent and the Most Merciful.

Special dedication for my beloved husband, my mother and my late father and for ummah.

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ABSTRACT

The main purpose of this research is to develop a Problem solving Process Rubrics (PPR) for assessing students' problem solving skills in engineering laboratory courses that employ project-based learning. A project-based learning laboratory (PB Lab) course at the Faculty of Electrical Engineering, Universiti Teknologi Malaysia was selected as the case study. The case study design was divided into three phases of data collection and analysis: Phase I (Identification of the problem solving process in the PB Lab course), Phase II (Development of the PPR), and Phase III (Validation of the PPR). Phase I involved qualitative data collection which consisted of document analysis, observation and face-to-face interviews. Four groups of electrical engineering students which consist of one PB Lab facilitator per group were observed. The data were analysed to identify the problem solving processes that occured in the PB Lab course. By using thematic analysis, five main problem solving processes namely problem identification, project planning, engineering design implementation, project analysis and solution evaluations are reported. Percent agreements were obtained from three experts to validate the results. In Phase II, the rubrics were developed from the information gathered in Phase I. Additional data which included documents, literature reviews and face-to-face interview were collected to support the rubrics' development. Finally in Phase III, the developed rubrics were validated by three experts in terms of the contents and constructs. As a result, the PPR were developed for the PB Lab course. The method of developing problem solving rubrics which focuses on the process of solving problems within the project-based learning laboratory context can be a guideline for engineering educators in developing assessment instruments using qualitative research in the future.

ABSTRAK

Objektif utama kajian ini dijalankan adalah bagi membangunkan Rubrik Proses Penyelesaian Masalah (PPR) untuk menilai kemahiran penyelesaian masalah pelajar dalam kursus makmal kejuruteraan yang menjalankan pembelajaran berasaskan projek. Kursus makmal pembelajaran berasaskan projek (PB Lab) di Fakulti Kejuruteraan Elektrik, Universiti Teknologi Malaysia telah dipilih sebagai kajian kes. Rekabentuk kajian kes ini dibahagikan kepada tiga fasa pengumpulan data dan analisis: Fasa I (Pengenalpastian proses penyelesaian masalah dalam kursus PB Lab), Fasa II (Pembinaan PPR), dan Fasa III (Pengesahan PPR). Fasa I melibatkan pengumpulan data kualitatif yang terdiri daripada analisis dokumen, pemerhatian dan temubual. Empat kumpulan pelajar kejuruteraan elektrik yang terdiri daripada seorang fasilitator PB Lab bagi setiap kumpulan diperhatikan. Data ini dianalisis untuk mengenalpasti proses penyelesaian masalah yang berlaku dalam kursus PB Lab. Menggunakan analisis tematik, lima proses utama penyelesaian masalah telah dilaporkan iaitu; pengenalpastian masalah, perancangan projek, pelaksanaan rekabentuk kejuruteraan, analisis projek dan penilaian penyelesaian. Peratus Persetujuan diperolehi daripada tiga orang pakar untuk mengesahkan keputusan. Dalam Fasa II, rubrik dibina daripada maklumat yang didapati dalam Fasa I. Data tambahan termasuk dokumen, sorotan kajian dan temubual bersemuka dikumpulkan untuk menyokong pembinaan rubrik. Akhirnya dalam Fasa III, rubrik yang dibina telah disahkan oleh tiga orang pakar dari segi kandungan dan konstruk. Hasilnya, PPR telah dibina untuk kursus PB Lab. Kaedah untuk membina rubrik penyelesaian masalah yang menumpukan kepada proses menyelesaikan masalah dalam konteks makmal pembelajaran berasaskan projek boleh dijadikan panduan bagi pendidik kejuruteraan dalam membina instrumen penilaian menggunakan penyelidikan kualitatif di masa hadapan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

EAC	-	Engineering Accreditation Council
OBE	-	Outcome Based Education
UTM	-	University Teknology Malaysia
PO	-	Program Outcomes
CO	-	Course Outcomes
PB Lab	-	Project-based Laboratory
FKE	-	Faculty of Electrical Engineering
KPI	-	Key Performances Indicator
PPR	-	Problem solving Process Rubrics

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

"Don't bring me problems, bring me solutions". This is one example of command that most engineers hear every day. Nowadays, engineers or the so called "problem-solvers" are faced with more difficult, high risks and sometimes unheard problems (Cronjie and Coll, 2008; Paton, 2010). In addition, Mohd *et al*. (2014) has also mentioned that in the 21^{st} century, engineering graduates must become good problem-solvers who can solve complex and multidisciplinary problems. Reports highlighted by many researchers have also revealed the skill of problem solving as an essential skill for all workers especially engineers (Jonassed *et al.*, 2006; Clough, 2004; Wankat and Oreoviez, 2015).

The need for engineering graduates to be proficient in problem solving has been highlighted by engineering accreditation boards of many countries as defined in the respective engineering programme outcomes. The National Academy of Engineering for instance, has identified that problem solving is an important skill for engineering graduates in the 21^{st} century (National Academy of Engineering, 2005). In the United States, ABET has listed eleven outcomes for engineering programmes

(Student Outcome 3a-3k) with outcome 3e particularly highlighting the problem solving skills requirement as follows:

> An ability to identify, formulate and solve engineering problems.
>
> (ABET, 2015:3)

In Malaysia, EAC (Engineering Accreditation Council) has established new and more specific programme outcomes (PO) for engineering programmes. Three (4(i)-4(iii)) out of eleven programme outcomes listed by EAC are related to problem solving skills as follows:

> PO1: Apply knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems.
>
> (EAC, 2012:2)

> PO2: Identify, formulate, research literature and analyse complex engineering problems reaching substantiated conclusion using first principles of mathematic, natural sciences and engineering sciences.
>
> (EAC, 2012:3)

> PO3: Design solutions for complex engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.
>
> (EAC, 2012:3)

EAC's aforementioned programme outcomes show the need for engineering students to acquire problem solving skills throughout their studies. On the other hand, recent studies have found that the ability to solve problems among engineering graduates are still low (Idrus *et al.,* 2010; Bernama, 2012; International Labour Organization, 2012; Yeen Ju, Mai and Selvaretnam, 2015). Thus, there is a need to develop proper assessment tools that can determine the level of competency in problem solving among engineering students. This is important to gauge the ability of the students to solve problems, which can then be used as a reference point to take the proper actions towards developing engineering students who are highly competent in problem solving

Assessment is the "heart" of students' experiences (Brown and Knight, 1994). It defines what students regard as important, how they spend their time and how they see themselves as students, and later as graduates. Nitko (2004) also defines assessment as a process of decision making to get the meaning on students' learning progress. It is the summary of students' learning which represents their improvement in certain topics or subjects, the difficulties they faced and their success. In short, assessment is an information feedback for the students (Pintrich and Schunk, 2002). Particularly in engineering education, assessment is seen as an important element that can enhance a learning process rather than just "something" to get marks from (Rust ,2002). Furthermore, assessment also plays a significant role in improving engineering education (Olds *et al*., 2005). Besides having a clear programme objective, engineering programmes need to have "a process of on-going assessment and evaluation that can demonstrate the students' achievements" (EAC, 2012). This indicates the importance of assessment not only for the students, but also in giving valuable information to the engineering accreditation bodies regarding the quality of the engineering students.

1.2 Background of Problem

The assessment of engineering students' problem solving skills using a proper tool is increasingly important as it can help justify the competent level of the students in this aspect for presentation to the industry. In fact, assessment using a proper tool can also become a factor that leads the students towards the process of problem solving itself. The developed assessment tool also allows the students to think and solve real world problems independently or in a group besides helping the lecturer facilitate the students' problem solving progress (Docktor and Heller, 2009; Schuwirth *et al*., 1999; Nair and Ngang, 2010).

Several researches related to problem solving (Deek *et al*., 1999; Docktor and Heller, 2009; Saunders *et al*., 2003; Anderson *et al.*, 2011) have reported the impact of assessment on students' problem solving skills. In addition, the assessment of problem solving skills can allow the students to practice problem solving (Anderson *et al.*, 2011; Saunders *et al.*, 2003) and improve their thinking skills in solving problems especially when dealing with real and complex cases (Schuwirth *et al*., 1999).

Various types of assessment tools and instruments to assess students' problem solving skills have been proposed and reported in literature. Examples of problem solving assessment tools are multi-part essay exams (Anderson *et al.*,2011), problem solving rubric (Docktor and Heller, 2009), case-based tests (Schuwirth *et al*., 1999), instrument related to de Bono's CoRT thinking tools (Nair and Ngang, 2010) and Philip's flowchart of problem solving model (Helmi *et al.*,2011). However, it must be highlighted that although problem solving is an important skill for engineers particularly, there is still no standard way to measure it (Docktor and Heller, 2009; Docktor *et al*., 2016). Most of the assessment tools designed to measure problem solving skills are focused on measuring the output or the correctness of the end results, rather than the process that the students go through to arrive at the end results (Schoefeld, 1985; Docktor and Heller, 2009; Docktor *et al*., 2016). It is important to stress that the solution to a given problem usually emerges after the students have gone through the problem solving process. Thus, by defining the problem solving process, the part of the process that the students are lack in can be identified and use as a basis to measure their problem solving skills. This is in line with Baker (1989), Zimmerman (1990) and Moreno (2010) whom highlighted that most of the improvements in solving problems come from the results of deliberate evaluation of the problem solving process that students applied in finding the solutions.

In an engineering curriculum, students' problem solving skills can be assessed not only in classroom settings but also in laboratories. Laboratory work is important in an engineering curriculum as it integrates theory and practice. Through laboratory work, students can practice engineering technically, improve their problem solving skills, practice working in teams and get industrial exposure through work integrated learning (Feisel and Rosa, 2005; Krivickas, 2007; Ionescu, 2015). Assessment of students' problem solving skills in laboratory courses must not be based on their theoretical knowledge only but also on their hands-on work. According to Salim (2012) and Pickford and Brown (2006), the conventional assessment method addressed in laboratories which is based on the laboratory reports produced by the students are not able to truly assess their performance, particularly on their problem solving skills related to both theory and practice. Hence, the importance of developing an assessment tool that can specifically measure students' problem solving skills based on both aspects.

According to Moreno (2010), performance assessment is one of the assessment type that can be used to assess problem solving skills due to its characteristics that focus on subjective skills. This type of assessment concentrates at the learners' progress rather than just on the end results. It looks at how students use their knowledge and skills to complete a task or product given, on realistic contexts (Nitko, 2004). Unfortunately, there is some limitation when assessing students by performance. Performance assessment takes more time to construct and at the same time it lacks in reliability. This is because different performance assessment require different scoring. Moreover, the latter is related to the students' aptitude rather than to what they have been taught (Shavelson, Baxter and Pine, 1992). In order to overcome the limitation of performance assessment, Stiggins (2005) has reported the use of scoring rubrics as a reliable and valid assessment tool that can be used to evaluate students' performance.

Rubrics are the scoring scales that describe the criteria for grading subjective assessments (Moreno, 2010). Many studies have revealed that rubrics that are given ahead of time, can guide the students' attention and enhance their performance (Arter and McTighe, 2001). The effectiveness of a scoring rubric as an assessment tool that can lead students to achieve the desired outcomes has been proven by De La

Paz (2008). This is in line with the statement made by Huba and Freed (2000) on assessment as follows:

"Learning increases, when learners have a sense of what they are setting out to learn, a statement of explicit standards they must meet, and a way of seeing what they have learned."

The above quote explains the need for clear observable indicators that can lead students towards improving themselves once identifying their weaknesses and level of ability. Most researchers in fact, uses scoring rubrics as the main selection in assessing students' problem solving skills (Docktor and Heller, 2009; AACU, 2010; Alfrey and Cooney, 2009; Center for Teaching and Learning Assessment, 2014). Considering the effectiveness of rubrics as a performance assessment tool, a specific scoring rubric to assess students' problem solving skills in a laboratory setting involving both theory and practice is proposed in this study.

1.3 Statement of Problems

The earlier discussion have presented the issues occurred in assessment of problem solving in the laboratory context. Through the discussion, the previous research are found to have limitation in assessing problem solving in three main issues in laboratory context; (a) the lack of research on development of assessment in laboratory; (b) the method of assessing problem solving is still not accurate; and (c) lack of research in developing assessment that focused on specific problem solving process.

Hence, this study focuses on developing a rubrics assessment tool that assess the problem solving skills in the laboratory context. The researcher attempted to fill the gap of the problem solving assessments' issues (as reported above) by developing Problem solving Process Rubrics (PPR) that can be used as formative assessment tools for assessing problem solving skills in the project-based learning (PBL) laboratory. Thus, one of the PBL laboratory in Universiti Teknologi Malaysia (UTM) which is one of a technology and engineering based public university in Malaysia, have been selected as a case study. As one of the universities that has successfully produced engineering graduates in Malaysia since the 1970's, the outcomes of problem solving skills among UTM engineering students have been emphasized to fulfil the demands of many stakeholders, especially the industries. A good assessment tool not only align with the outcomes of problem solving, but can also truly interpret and measure the levels of students' problem solving competencies before they graduate have to develop.

1.4 Research Objectives

The main purpose of this research is to develop Problem solving Process Rubrics (PPR) for project-based learning in engineering laboratory course. In this study, Project-based Learning laboratory (PB Lab) course at Faculty of Electrical Engineering, Universiti Teknologi Malaysia is selected. Three research objectives are identified as follows:

a. To identify the problem solving process that occur during the PB Lab course activities to be included in designing the PPR.
b. To construct the rubrics' criteria, descriptors and levels of performances which relate to problem solving process that occur in PB Lab course to be included in the PPR design.
c. To examine the validity of the PPR designs including the contents and constructs in assessing problem solving skills for PB Lab course.

1.5 Research Questions

To achieve the research objectives (RO), the following research questions (RQ) were formulated.

RQ1. What are the problem solving process that occur during the PB Lab course activites?

RQ2. What are the rubrics' criteria, levels and descriptors which relate to problem solving process that occur in PB Lab course to be included in the PPR design?

a. What are the criteria of the problem solving process which are appropriate to be included in the PPR design?
b. How many levels of students' performances that need to be included in the PPR design?
c. What are the descriptors of students' performances which are appropriate to be included in the PPR?

RQ3. Is the PPR design valid in terms of content and construct in assessing problem solving skills in PB Lab course?

a. Content validity:
   Does the PPR content measure the required problem solving outcomes that it intends to measure?
b. Construct validity:
   Are all of the important aspects of problem solving outcomes evaluated through the PPR?

1.6 Conceptual Framework

For this study, there are three concepts including the theory and model which have been focused in this research namely, Constructivism theories, Woods *et al.* (1997) problem solving process model and Mertler's (2001) rubric development model. The conceptual framework of this research is summarised in Figure 1.1.

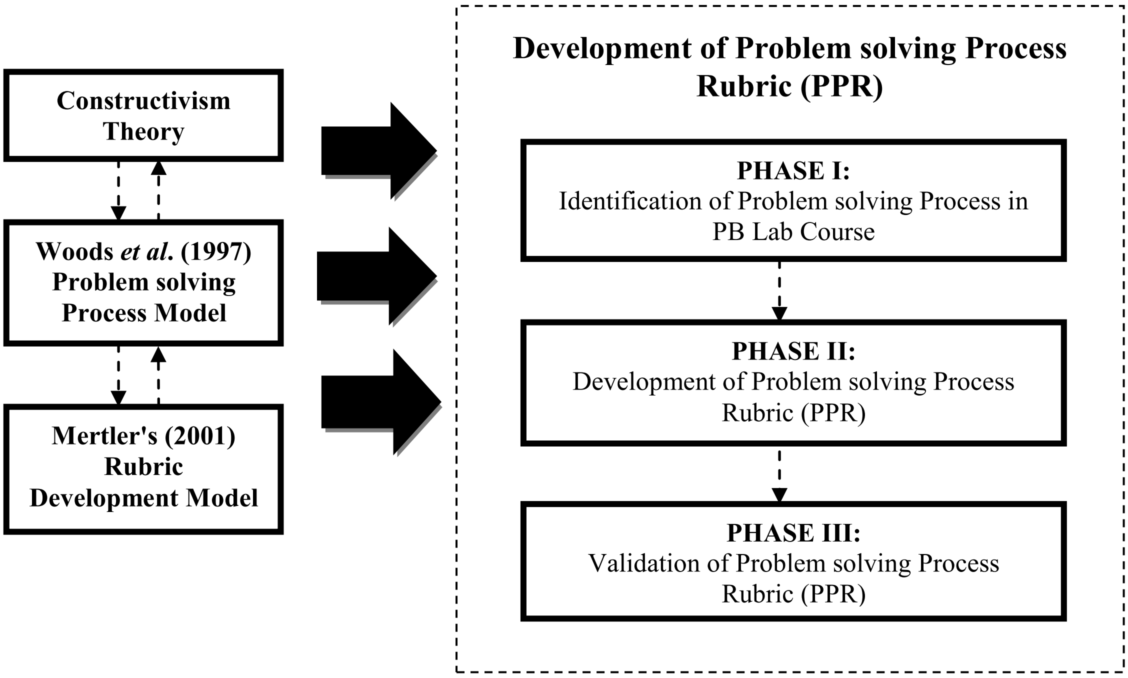

Figure 1.1: Conceptual Framework

Theory of Constructivism. This study is based on constructivism theories inspired by Piaget (1954) and by Vygotsky (1978). According to Piaget (1954), people construct meaning or knowledge individually based on their personal experiences through interacting with others and their surroundings (Moreno, 2010; Simpson, 2001). This theory suggests that each individual can actively construct meaning or knowledge in his or her mind (Greeno *et al.*, 1996; Eggen and Kauchak, 2001). This has been proven by Piaget's work, which showed that individuals who interact with others and the environment construct knowledge by organising, assimilating and accommodating new information in their cognitive structures (Moreno, 2010). Vygotsky (1978), reviewed Piaget's work and further developed the concept in constructivism theory which described that the learning process happens when the learners share their individual perspectives or understanding with others to construct meaning together (Gauvain, 2001). Vygotsky's concept differs from the concept derived by Piaget (1954) that focuses on individual thinking process, whereas Vygotsky emphasis social interaction as a mechanism to promote individual thinking (Palincsar, 1998).

Piaget and Vygotsky's theory that are fundamental to the idea of constructivism is relevant to this study because in the PB Lab course itself, students are working in groups of three to four. It can be seen that after each group obtain their problem to be solved in the PB Lab, they start to reflect the problem given in their own words by discussing with group members and PB Lab facilitators. Each member will then try to understand the problem, learn how to interpret the data, pay attention to the explanations, and apply the right concepts to solve the given problems. All of these are done by interacting and engaging in discussions with team members. This interaction whether it is between students and other individuals such as PB Lab facilitators, lab technician and the learning environment, helps each of the students to learn and construct knowledge in their mental structure as highlighted in the constructivism theory. It is also important to highlight that this theory have been determined to relate one of the students' thinking process which is problem solving (Sing, 2015; Hardin, 2002).

Woods' (1997) problem solving process model. Another concept or model that has been refered in this study is Woods' problem solving process model (Woods *et al*., 1997). Woods and his team from McMaster University are the constructivists who contributed in implementing problem-based learning (PBL) and have been actively developing problem solving skills among engineering students (Helmi *et al.*, 2011; Rugarcia *et al.*, 2000). The problem solving process listed by Woods *et al*. (1997) focused on the process of thinking when solving problems. There are six steps of Woods' model starting from "I can" stage, define problem, explore problem,plan the solution, do it and finally, "look back" stage. Woods *et al*. (1997) poblem-solving process have been choosen for this study because it is more relevant to the context of engineering courses and it was developed specifically for engineers (Mourtos *et al.,* 2004). In the PB Lab course, the problem solving process has been identified in the first week, when the students were required to figure out the main problem at hand. Each student tried to understand and explore the main problem, or the issues that occur, before proceeding to strategies development. Moreover, the process in solving the problem becomes more critical when it comes to interpreting the results obtained after implementing the selected solution. In this phase, the discussion sessions among team members, and question-and-answer sessions with the facilitators helped the students to define the problem more accurately.

Mertler's (2001) rubric development model. The Mertler's rubrics development process has been selected to be used as a guideline in developing Problem solving Process Rubrics (PPR) in this study. Mertler's rubric development which focuses on the process in developing the valid rubrics has been chosen because it has been developed based on compilation from various sources of rubric development model such as Airasian (2000), Airasian (2001) and Nitko (2004). There are seven steps of rubrics development process proposed by Mertler. It starts from selecting the learning objectives (LO) to be examined, determining the students' attributes that demonstrate the LO, brainstorm the outcome of the attributes, select the appropriate levels of performances and descriptors to be included in the rubrics and finally, test and refine it (Mertler, 2001). In designing the rubrics, the step-by step process of rubrics' development proposed by Mertler's (2001) guided the researchers to focus on the content of the rubrics' design itself including the rubrics' criteria, descriptors and students' level of performances.

Based on the discussion above, it can be stated that the theory and models discussed, were interrelated to each other in developing Problem solving Process Rubrics (PPR) for assessing students' problem solving process which is the main objective of this study. The concept in Constructivism theory is described that learners construct knowledge in their mind based on their interaction with surrounding and theirs peers. Here, the constructivism highlighted that the learning occurs when there are "thinking process" and the important mechanism that leads to this thinking process is via "interaction".Both of these key words; thinking process and interaction were similar with the keywords in Woods *et al*. (1997) problem solving process model which stressed that the "thinking process" happens when the students solve the given problem whether individually or in groups. In solving problem, the "interaction" with group members or other stakeholders are also needed to help learners to think different ways to solve problems (Moreno, 2010) as well as to help learners to reflect their thinking. Due to that, in assessing problem solving process, Woods *et al.* (1997) suggested that performance assessments should be considered. Performance assessment is effective in measuring subjective skills such as students' thinking skills, transferability skills and others (Darling-hammond *et al.*, 2010; Moreno, 2010). One of the way to increase the reliability and objectivity of it is by using rubrics as scoring tools. Hence, Mertler's rubrics development concept has been used in this study in developing the PPR for Project-based Laboratory (PB Lab) course.

1.7 Significance of Study

Problem solving is currently a skill that is required in both education and industry. In view of the broad scope of the engineering profession, future engineers will need to adapt to rapidly changing work environments and technology, work across different perspectives, and most importantly, and be able to solve unexpected real-world problems. Due to these requirements, this research is conducted to enhance students' problem solving skills based on assessment strategy. According to Watkins and Hattie (1985), types of assessments used do have a significant influence on students. This align with the statement made by Boud (1995) that stressed:

> "Students can, with difficulty, escape from the effect of poor teaching, but, if they want to graduate, they cannot escape from the effects of poor assessment"
>
> (Boud, 1995: 1)

This quote have motivate the researcher in researching and deeply understand the impact of good assessment ; one out of three important elements in constructive alignment (Biggs and Tang, 2007). Therefore, this research focuses on designing a specific rubric based on the problem solving process that can effectively assess problem solving skills in an engineering laboratory context. The other contributions of this research are as follows:

a) Students

By using rubrics, students' performances can be improved. It is because of students would know and understand the level and criteria to be achieved, and they would also know how to perform better in the future (Stiggins, 2004). Specifically, for problem solving assessment, rubrics helps students to identify their weaknesess and ability in solving problems effectively based on the criteria, descriptors and the levels of students' performances include in the rubrics. It is like a "self-assess" tools that can promote students' learning (Koh and Lee, 2006; Jonsson and Svingby, 2007).

b) Educators

Instead of benefit for students, rubrics is also importance to educators. Rubrics help the educators to evaluate the students through the criteria listed in them, and enhance students' performances (Schafer *et al.*, 2001). Besides, rubrics also can be used as a guideline for the educators, e.g. to promote and implement "problem solving process" in their teaching and learning instructions, especially in the engineering laboratory context, as stated in the rubric's criteria. Besides that, the rubric's results also provides educators with detailed information about their teaching and learning instruction effectiveness, and which students lack the required skills (Guskey, 2013).

c) Engineering Educational instituition

In engineering education context, the development of rubrics have significantly effect the quality of the engineering gradutes produce by universities every years. By using rubrics, the validity and reliability of the students' performances can thoroughly measured and not depends on the grades only. All these have lead to high consistency of judgement when assessing subjective skills such as problem solving skills (Jonsson and Svingby, 2007). Same goes to the development of problem solving process rubrics (PPR) in this study, the PPR would help in guiding on the method how to assess engineering students' problem solving process in the laboratory context. As known, laboratory is the place where our students transfer most of the concept learned in the class to practical work. Many process happened during this lab session and it is disappoint if the assessment used cannot thoroughly assess the "process" happened. Its cannot be denied the impact of valid and good rubrics to education instituition as a "transparently assessment" which would help shape the students' problem solving skills (via process) and increase the numbers of quality engineering graduates that fulfil the requirement of program outcomes listed in the engineering accreditation body.

d) Industry

As previously discussed, engineering students should possess good problem solving skills should they desire to be hired by an engineering company. The development of the problem solving process rubrics in this study also has an impact on the industry. The criteria designed in the PPR are aligned with the criteria required by the Engineering Accreditation Council (EAC), which are based on the skills in demand by industries. This illustrated that the rubrics can be used as a benchmark to indicate students' weaknesses before they are employed.

Finally, it is hoped that the process in developing a specific problem solving process rubrics in this study, especially in the engineering laboratory context, can facilitate and guide education community to design a valid problem solving process rubrics in the future which can transparently present the actual level of competencies of engineering students in solving problem.

1.8 Scope and Limitation of the Study

The main objectives of this research is to develop a Problem solving Process Rubrics or known as PPR in assessing students' problem solving skills in the project-based learning laboratory. This study is based on qualitative research methodology where case study design have been selected. It is important to highlight that this research only focuses on assessing the the problem solving process in enhancing engineering student's problem solving skills. Besides, it is important to highlight that this study is focused on the problem solvings process that occurred in the project-based learning (PBL) specifically in the engineering laboratory context. For this study, the project-based laboratory (PB Lab) course implemented at the Faculty of Engineering (Electrical) (FKE), Universiti Teknologi Malaysia (UTM) have been choose as a case study setting. There are eleven laboratories operating under six different courses (SEE, SET, SEM, SEC, SEL and SEI) that are involved in this PB Lab course. However, in collecting the data of this study, the laboratories involved have been selected randomly by the researcher due to the constraints of the numbers of PB Lab facilitators involved. The participants who were involved in this research are also specifically from the electrical engineering domain including fourth year students from FKE who go through the PB Lab course and the PB Lab facilitators who do not have formal training in using rubrics.

In addition, in this research, the current programme outcomes and learning outcomes of the PB Lab are reviewed, and no changes are made to them. These outcomes are reviewed to determine the skills of problem solving that this course aims to deliver to the students. Apart from that, in this research, the new rubrics called Problem solving Process Rubrics (PPR) have been designed to assess students' problem solving skills, in the PB Lab context. No changes were made to the existing PB Lab rubrics.

1.9 Definition of Terms

The following terms are commonly used in this research:

a) Problem solving

There are various definitions for "problem solving" that are proposed by many researchers. The definition proposed by Jones *et al*. (1997) and Jonassen (2003), which highlights the "process of thinking", has been selected by the researcher as a guideline in this study. According to Jones *et al*. (1997) and Jonassen (2003), problem solving is "an individual step-by-step thinking process; defining a problem, obtaining background knowledge, generating possible solutions, searching for information, and testing the hypothesis to arrive at the final solution". The definition proposed by them was relevant to the context of this study where in solving problems in the PB Lab course, students have to go through all the process to achieve the final solution.

b) Problem solving Process

In the context of this research, the problem solving process have been refered from Woods *et al*. (1997). There are six process proposed by Woods *et al*. (1997) that students must go through to solve problems; (a) I can, (b) define problem (c) explore the problem, (d) plan the solution, (e) implementing the solution and (f) conducting evaluation (look back). Although the process listed by Woods *et al.* (1997) have been refered, the real problem solving process happened during the PB Lab session are still been determined in Phase I to be include as a criteria in the PPR design in Phase II.

c) Project-based Learning

Project-based learning (PBL) is a student-centered learning strategy (Mills and Treagust, 2003) in which students are organized in groups and dealing with the project which is closer to the actual work as an engineer. The project given also based on challenging problems occurred that involves students to actively plan the solution and solve the problem in a group (Martínez *et al.* 2011; Mills and Treagust, 2003). In this research, the project-based learning in laboratory (PB Lab) implemented in the Faculty of Engineering (Electrical) have been selected as a case study setting.

d) Rubrics

Rubrics are scoring scales that describe the criteria for grading subjective assessments (Stiggins, 2005). Besides that, it is also defined as an assessment tool that provides detailed criteria of a students' work, including description of levels of performance quality on the criteria (Brookhart, 2013). There are two types of rubrics; holistic and analytics. However, in this research, the analytic rubrics that assess a step-by-step problem solving process have been designed based on the Mertler's rubrics development process (2001) to easily determine the problem solving skills among students individually. Importantly in designing PPR for this study, there are three part of rubrics' design which are rubric's criteria, rubrics' descriptors and rubric's levels of performances. Rubric's criteria is usually based on learning targets lecturers want to refer to when evaluating students' works or performances (Arter and Chappuis, 2007). It is important to identify the correct criteria that should be incorporated in the rubrics so that they can be aligned with the learning objectives. In this research, the criteria of problem solving process are selected to be focus on. Besides that, to ensure the validity and reliability of rubrics, proper descriptors should also be formulated based on a specific criterion (Arter and Chappius, 2007). In other words, the descriptor is the specific description for each criteria by which the work or performance will be judged. Lastly, another part of the rubric's format which is really important in assessing students' work is the rubric's levels. The levels of performances describe the quality levels of the tasks that have been performed by students (Stevens and Levi, 2005). Some studies reported that there are two ways in dividing the levels such as based on "numbering scales" or based on "words" that represent the performances of students (Zimmaro, 2007).

e) Assessment

Assessment is one or more processes that identifies, collects, and prepares data to evaluate the attainment of student outcomes and programme educational objectives (ABET, 2011; Huba and Freed, 2000). Woods *et al*. (2000) also defined assessments as a judgement on how much the measurable criteria achieve the goal based on pertinent evidence. This means that assessments can reflect whether the criteria that students have to perform during a learning process are achieved. Hence, this study has selected and applied the assessments strategy in order to assess students' problem solving skills in project-based laboratory course.

f) Performances Assessment

Performance assessment is a type of formative assessment that requires students to use their knowledge and skills to complete the task or produce the product in more or less realistic context (Moreno, 2010). A performance assessment is a formative assessment which assess students continuously and require students to demonstrate specific skills and competencies by producing something i.e. carrying experiments. Hence, this study will developed one of the performances assessments tools which is rubrics which can assess students more reliable and effective (Stiggins, 2005).

g) Validity

Validity in this research refers to the validity of effective assessments. A valid assessment is defined by characteristics that measure what they intend to measure (Nicholson, Gillis, and Dunning, 2009; Moreno, 2010). Besides, validity is also related with the process of collecting the evidence that supports the interpretation made based on student responses for specified assessment used (Moskal and Leydens, 2014). There are two types of validation which are used by the researcher to validate the assessments: content validity and construct validity (Jonsson and Svingby, 2007; Moreno, 2010; Nicholson *et al*., 2009). Content validity is based on the "content" of the assessment itself, and whether it truly reflects the assessed students' knowledge. In contrast, construct validity is when the assessment has been designed not only to measure the student's knowledge, but also to measure the particular skills that are displayed through the students' explanation or results (Moskal and Leydens, 2014). In this research, both content and construct validity have been reviewed using the "experts review strategy" to make sure the PPR are valid, and truly measure the problem solving skills among students.

1.10 Organization of the Thesis

This thesis consists of eight chapters and was organized as follows. Chapter 1 present the research background, statement of problem, research questions, conceptual framework, significant of study and scope and limitation of study. Chapter 2 presents review of related literature that discussed theory of learning, constructivism and problem solving, problem solving, problem solving process, project based learning, assessment,performances assessment, assessment of problem solving and rubrics. Chapter 3 presents the methodology used in this study including the research design, operational framework,data collection, data analysis and validation method implemented in this study. Chapter 4,5 and 6 provides a description of findings and data analysis from Phase I, Phase II and Phase III of this study. Chapter 7 presents the discussion of the findings and finally Chapter 8 presents the conclusion and recommendation for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter which covers literature reviews, discussions are centred on the following areas: theories of learning, definitions and models of problem solving skills in general and in engineering context, as well as assessment. Since this project is focused on designing rubrics in assessing problem solving skills, a thorough discussion containing discussions on the assessment for problem solving, rubric design and its development process is also included.

2.2 Theories of Learning

Over the past century, people have tried to understand how people learned and how to encourage learning. Variety learning theories viewpoints occurred in explaining how people acquire knowledge. Some of the famous researchers that promoted their findings were Watson (1913), Pavlov (1955), Piaget (1954), and Vygotsky (1978). Each of these researchers have come up with the different views of learning that helped educators to choose and apply the most relevant ones in their teaching process. Some of the dominant learning theories were within the domains of Behaviourism, Cognitive and social Constructivism. These theories have been widely applied in educational systems to enhance students' learning.

In Behaviourism Theory, the behaviourist viewed learning as a change in observable behaviour, thought and feeling that occurs as a result of experiences (Moreno, 2010). There are two types of theories of Behaviourism, known as classical and operant conditioning. The classical conditioning relates to the Pavlov's ideas that discusses about the occurrences of stimuli and responses in changing the subjects (Moreno, 2010). Stimuli can be represented as sound, smell or touch of something and the process of associating these stimuli can automatically produce natural responses (learning) from the subjects. It is contrast with the operand conditioning concepts that discusses about how subjects learn to operate on their environment by giving the reinforcement (Moreno, 2010; Hardin, 2002). If the behaviour is followed by giving the positive reinforcement, the behaviour might be repeated again. In learning, these reinforcement strategies have been widely used in enhancing students' learning. Although it has been recognised as one of the factors in changing the students' behaviour towards learning, the change in terms of students' thinking and understanding of learning in this theory have not been determined (Hardin, 2002).

Due to that, the Constructivist psychologist highlighted the Cognitive view of learning in terms of thinking to fill the gap. There are two types of theories under Constructivism which are Cognitive (Piaget, 1954) and Social-Cognitive (Vygotsky, 1978). Learning as defined by Cognitive researchers is an individual natural tendency in constructing knowledge in their mind by observing and interacting with environments, whereas the Social-Cognitive people discussed learning is when the learners share individual perspectives with others to construct understanding together (Gauvain, 2001). Both of these theories of Constructivism are focused on students' thinking process and the influences of environment towards this thinking. By discussing the three learning theories above, it can be highlighted that the behaviourist's perspectives on learning are different with Constructivist because the changes that might happened in people's thinking and belief are totally disregarded.

2.2.1 The Relation between Constructivism Theory and Problem solving Skills

The relation between the Constructivism Theory and problem solving skills cannot be denied. Hardin (2002) reported that when the theories of learning develop, understanding of the process of problem solving also evolves accordingly. There are different views of problem solving in the perspectives of Behaviourism and Constructivism. The behaviourists' view of problem solving is a "process that develops through positive and negative reinforcement elements" (Hardin,2002). Behaviourists tend to explain that the existence of problem solving skills cannot be seen if no reinforcement mechanism is involved. It is contrast with the Constructivism people's views that conclude problem solving as a "process that includes introspection, observation and the developments of heuristics" (Sing, 2015). This research has opted for the Constructivism view on problem solving because the concept fits the PB Lab context well; students' skills of solving problems are enhanced via thinking process.

Cognitive Constructivism and Social Constructivism are the learning theories, which have been inspired by the work of Piaget (1954) and Vygotsky (1978). It is emphasized on:

a) How learners construct knowledge and understanding in their mind.
b) Learners develop understanding in their mind via sharing their own perspectives and interact with others and surrounding.

Based on the above, it clearly showed that there are two main elements in Constructivism Theory which are related to "process in mind" and "interaction with surrounding". Both of these key words are similar with the elements included in the step-by-step process of problem solving. It is because in solving problems, the "thinking process" happened at the first steps which are identifying the problem. Besides, in solving problem, the "interaction" with group members or stakeholders is needed to help learners to think of different way to solve problems (Moreno, 2010), as well as to help learners reflect their thinking. Both constructivism theory and steps in solving problems triangulate to each other. In Constructivism learning environment, the teaching and learning (T&L) approach are more on student-centred learning, where students are active in searching, understanding and getting knowledge. Some of this active learning approach are problem-based, project-based and case study learning (Mohd *et al.*, 2005; Tam, 2015 and Azli *et al.,* 2012).

There are also several elements that can be triangulated between Constructivism Theory and problem solving steps. One of the elements was regarding the responsibility of the educators during learning sessions. In the perspectives of Constructivist, educators are responsible to stimulate and trigger the students to develop their own understanding (Sing, 2015). This is relevant with the problem solving, because in facilitating the students to solve the problem, educators are not allowed to directly lead them to the solution but they have to be like a facilitator who only facilitates the students and triggers questions, so that they have to think to create the solution. It coincides with the statement made by Sing (2015) and Tam (2015), which is to make sure the students become active learners in class, the responsibility of the educators are also important. The educators must create two way communications while teaching so that the students will be able to share their opinion, give feedback or comments and explain their understanding (Fleming and Alexander, 2001).

On the other hand, another element that is needed by Constructivist and is also required in solving problems was a good learning environment. Learning environment was one of the criteria in the social Constructivism Theory (Vygotsky, 1978). Students are encouraged to interact with their surrounding environment such as their peers, lecturers and others to develop an understanding together. Importantly, the understanding that is created within the groups will lead to individual understandings (Gauvain, 2001). This is the same in the process of solving problems. According to Moreno (2010), one of the strategies in enhancing students' problem solving skills is by using social interactions. This is proven to be one of the reasons in helping students think differently, and be able to solve problems. For example the activities in groups in this learning environment, discussion session with peers and lecturers are helpful for students to foster their skills. Besides, the educators' roles such as provoking the students with questions are important in making this learning environment active.

So, as discussed above, it clearly showed that Constructivism Theory is related with the problem solving skills that students must possess nowadays. The concepts needed by Constructivist are not contrary with the step-by-step problem solving process referred in this study which is from Woods *et al*. (1997). It is because the concepts required are the same which regards the needs of thinking process and social interactions.

2.3 Problem solving

Nowadays, problem solving has become one of the interesting skills investigated by many researchers all around the world. Many educators, especially those who are involved in professional curricula, have shown interest in problem solving skills to train students to become successful problem solvers. In this 21^{st} century, several definitions of problem solving have been proposed by many researchers. In a national report of higher education, Jones *et al.* (1997) gave a comprehensive definition of problem solving skills based on a survey of 500 policymakers, employers and educators. Jones defined problem solving as a step-by-step process: defining a problem, obtaining background knowledge, generating possible solution, search for the information, and testing the hypothesis to arrive at the exact solution. This definition was supported by Mourtos *et al.* (2004), who described problem solving as a process to obtain the best solution to an unknown or a decision, which is subjected to some constraints. Normally, a well-structured or an ill-structured problem is given to students to be solved. Students will try to understand the given problems and discuss with their group members; they will then come out with several proposed solutions. This form of learning activity is actually a process or steps of thinking students apply to solve problems. Sometimes, without being told, this process of solving problems is naturally adopted by students although the final state of problems remains unclear. This statement are also relevant with the statement made by Jonassen (2003), who also defined problem solving as "an individual thought process because the previous learned law can be applied in solving problems across situations". In real life, a lot of problems occur every day and this problem needs to be solved whether a person applied what he or she experienced before or practised the knowledge that they learned to ensure that the problem is solved. The process that the person applied based on experiences or previous knowledge can be stated as one of the strategies in solving problems (Moreno, 2010).

On the other hand, according to Martinez (2005), problem solving is a "process moving toward a goal but the path to the goal is not clear". This definition is nearly the same as the one given by Lovett (2002), who stated that problem solving, consists of various types of thinking that people have to apply to reach the desired end state, which is different from the first state. Apart from that, Charness (1998) defined problem solving as the activity that enables someone to survive a desired state from an initial one. Based on these definitions, it can be seen that most researchers defined problem solving as a "process", "types of thinking" and also "activities" that are applied by people to solve problems but with unclear final solutions. Although the definition of problem solving itself is ambiguous, the concept of the emergence of problem solving skills has been determined. The problem solving skill emerges when people try to get the best solution from various possible solutions to solve an unclear problem. Hayes (1989) defined problem solving situation as follows:

> "Whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross the gap,

> you have a problem. Solving a problem means finding an appropriate way to cross a gap."
>
> (Hayes, 1986:2)

Generally, various definitions and concepts proposed by researchers regarding the problem solving skills triangulate to each other's because each of the definition proposed, claims the important point about problem solving such as "process of solving problem" and "unclear solution". There are a lot of ways that people defined and proposed problem solving concepts to ensure people can apply it and use it in their discipline. As discussed above, some of the concepts of problem solving described by researchers in "sentences" (Jones *et al.,*1997; Mourtos *et* a*l.,* 2004; Jonassen, 2003 and Lovett, 2002) whereas there are also some researchers who defined problem solving in "stages or step-by-step process" (Woods et *al*., 1997; Polya, 1945; Dewey, 1910). However, for this study, the researcher tend to refer the definitions proposed by Jones *et al.* (1997) and Jonassen (2003) that defined problem solving as a "process of thinking" and have been used as a references in this study. This is due to the relevance of their definition of problem solving that matches with the concept of Constructivism Theory which focuses also on the "thinking process" that individuals build based on interactions with surroundings. Besides that, in terms of "problem solving step-by-step process", the Woods *et al.* (1997) Problem solving Process has been chosen to be a base in this study.

The details on process of problem solving proposed by many researchers including the Woods *et al.* (1997) Problem solving Process is discussed below.

2.4 Problem solving Process

Recently, the need for problem solving skills among students has slightly increased. This leads to the development of many ways representing step-by-step process in solving problem. The process of solving problem that is implemented during class sessions can enhance the effectiveness of teaching and learning (T&L), especially when applied experientially. Nowadays, there are various steps of problem solving proposed by researchers. Some of the well known problem solving process found are proposed by Dewey (1910), Polya (1945) and in the engineering domain were from Woods *et al.* (1997) , Deek *et al.* (1999) and Dym and Little (2000). Table 2.1 shows four different types of problem solving process that have been implemented and used across many domains.

Table 2.1: Studies on the Steps of Problem solving Process

Authors/ Years	**Step one**	**Step two**	**Step three**	**Step four**	**Step five**	**Step six**
Deek *et al.* (1999)	Problem formulation	Solution planning	Solution design	Solution translation	Solution testing	Solution delivery
Woods *et al.* (1997)	I can	Define problem	Explore problem	Plan the solution	Do it	Look back
Dym and Little (2000)	Problem Definition	Conceptual Design	Preliminary Design	Detailed Design	Design Communication	
Dewey (1910)	Identifying the problem	Representin g the problem	Selecting the strategy	Implementi ng the strategy	Evaluating the results	
Polya (1945)	Understanding the problem	Devising the plan	Carrying out the plan	Looking back		

Based on Table 2.1, four types of problem solving step-by-step process that have been proposed by several researchers: 6-step (Deek *et al*., 1999); 6-step (Wood *et al*., 1997);5-steps (Dym and Little,2000); 5-step (Dewey, 1910); and 4-step (Polya, 1945). Each of these processes has been implemented and used based on its relevance in different domains. For example, Polya in his model identified four main process of problem solving which are (a) understanding the problem, (b) devising the plan, (c) carrying out the plan and (d) looking back. Each of the process has its own target such as in stage one, understanding the problem required students to determine the goal of the problem by extracting and assimilating information. Next, devising the plan stage requires the students to plan some possible solution and try to implement it in the next steps. Although the Polya's steps are seem to be to short and general, but this problem solving process has been used widely in the mathematical domain (Hardin, 2002).

On the other hand, Dewey (1910) who is one of the well-known Constructivists (Creswell, 2008) person has originated five steps of problem solving process in his study which are (a) identifying the problem, (b) representing the problem, (c) selecting the strategy, (d) implementing the strategy and finally, (e) evaluating the strategy. Although the Dewey's problem solving process has been proposed since the past 30 years, but, his work are still being referred by many current researchers such as Anderson (1993), Simon (1999), Alfrey and Cooney (2009) and Moreno (2010). The Dewey's model are mostly used and chosen by many psychologists and computer scientists to be applied in their domain (Moreno, 2010). This is due to its characteristics which can be generalised and applied to any learning process.

Besides, Deek *et al.* (1999) with his team has introduced six problem solving processes which have already been implemented among the first year students at New Jersey Institute of Technology (NJIT). It consists stages starting from problem formulation, solution planning, solution design, solution translation, solution testing and solution delivery (Deek *et al.,* 1999). At the early stages of this process, the students need to understand the problem given by writing or asking questions before they proceed to design the solution. The design solution phase needs the students to organise and refine the problem component into sub-components including the specification of dataflow and algorithmic logic. Next, the solution that has been designed will be translated and tested to test the code and modifying of the code. Finally, the result of the solution will be presented and delivered by students (Deek *et al.,*1999). This Deek's model is relevant to be used in engineering domain but it is much more relevant to be applied if the case related to problem solving in programming development.

Dym and Little (2000) has proposed a problem solving process which relevant to engineering education context. However, based on the discussion by Sobek and Jain (2004) shows that this process is more relevant to be used in engineering design subject because its defined series of activities referring to the artificial development based on initial specification. Lastly, the fourth model of problem solving process discussed here is by Woods *et al.* (1997). Woods and his team at McMaster University have proposed a six-step problem solving process including the steps of motivation such as:

1) I can
2) Define problem
3) Explore problem
4) Plan the solution
5) Do it
6) Look back

This model has mostly been referred by engineering researchers and engineering educators that want to apply this problem solving strategy in their teaching session. According to Wankat and Oreoviez (2015), throughout the years, the Wood's model has slightly changed. The first step of this model includes the motivational element where the "I can" stage has been included. This stage is an important stage that can build up the students' motivation before they proceed to define the problem (Scarl,1990). Normally, at this stage the educators are responsible to give some explanation regarding the topic or some exercise that can help students refresh their previous knowledge (Richardson and Noble, 1983).

Then, the second step by Woods is defining the problem. At this stage, the students need to draw or illustrate some diagram that can help them understand the problem well. This stage requires students to visualise the need of the problem. However, according to Lan *et al.* (1998), at this stage, most students tend to rush and neglect then jump into the conclusion. This situation can affect the process of the solving problem itself and the students can easily be stuck at the next phase of solving problems. The next step of Wood's model is the exploring phase. This explore stage or called as "ponder" and "think about" stage are added into Wood's model after he determined that this stage was a beneficial stage for an expert problem-solver (Wankat and Oreoviez, 2015). Normally, expert problem-solvers will explore the problem by triggering themselves the question related to the problems until the need of the problem are clearly understood. It is contrast with the novice problem-solvers who normally neglect this stage. So, it is the educator's responsibility to train and guide them during this phase.

Once the problem is identified, the next step is the planning step. According to Bloom and Broader (1950) a good problem-solver spends more time planning the solution compared to those who are a poor problem-solver. This stage is important to the problem-solver to determine the possible solution that can be used to solve the problem. Some of the strategies that might help in clearly planning the solution to the problem, was by using flowcharts (for long problem), algorithms (most used for well-defined problem) and heuristics (for ill-defined problem) (Moreno, 2010; Wankat and Oreoviez, 2015; Simon, 1999). Do it, is the next step after the planning phase, which involves the implementation of the plan. This step is easily done if the planning stage is clear and organised. After implementing the plan, the next step is to check the solution. This stage is important in the problem solving process because it is the stage where the correctness of the results will be determined and the problem solution is justified. Normally, at this stage, the students usually compare the result that they have with the possible answer based on the data from their previous knowledge. Finally, the last step in Wood's model is to generalize. This process is needed in completing the problem solving process because it requires students to reflect and give feedback about what they learn and understand during solving the given problem. This is the stage where most of educators will assess the students' understanding and their problem solving skills.

So, based on the reviews made, it can be seen that most of the model proposed have been used widely in various domains. The shortest problem solving process was proposed by Polya in 1945, which are four stages while the longest problem solving process discussed is from Deek *et al.* (1999) and Woods *et al.* (1997). According to Woods *et al.* (1979), the problem solving process is relevant if it is between four to fifteen steps. But, if the steps proposed are less than four, it would be to short and not as detailed whereas, if it is longer than fifteen steps, it would be too long and not suitable to be applied. Based on the four models of problem solving process discussed above, it can be seen that each researchers refer to the similar process but the differences were in terms of its terminology, terms and sequences that have been used in their domain. This statement has also been agreed by Helmi *et al.* (2011), who also stated that the problem solving process is divided into three foundational phases; the definition phase, strategy phase and solution phase.

However, when all the models of problem solving process above are compared with this research's objectives, it can been seen that some of the models does not suit this study due to its process relevant to certain domain only. It can clearly be determined based on the researchers or educators who referred them. Among the four problem solving process discussed above, the model of Woods *et al.* (1997) is the most relevant to this study which focuses on developing problem solving for engineering students, whereas, other models of problem solving process are much more well known in mathematical, psychologist and sciences domain (Moreno, 2010). Besides that, several studies found that Woods *et al.* (1999) problem solving process has mostly been referred by the engineering people such as Mourtos *et al.*(2004), Felder *et al.* (2000), Helmi *et al.* (2011) and Mohd *et al.* (2005).

Helmi *et al.* (2011) have applied Woods *et al.* (1999) model as a concept applied in developing their Engineering Problem Solving Instruments (EPSI) to measure students' thinking in problem solving after undergoing Cooperative Problem-based Learning (CPBL). Instead as a concepts in developing problem solving instrument, Woods *et al.* (1999) problem solving processes also been refered by Mourtos *et al*. (2004) in order to implement problem solving in their mechanical engineering classroom. Based on Mourtos *et al*. (2004), presented that the Woods' process have been used in teaching problem solving for open-ended problem regarding; (a) Termodynamic; (b) Fluid mechanics and (c) Heat tranfer. The Woods' problem solving process have been followed one-by-one by the students and the results reveals an improvement in terms of students' confidence level in solving real and complex problem. This clearly shows the relevancy of the Woods *et al.* (1997) in engineering education context.

The work done by Woods and his team is not only focused on the context of problem solving only, but they are also experts in implementing problem-based learning in the chemical engineering faculty, as well as proposing the elements of assessment that it suitable to assess problem solving skills among engineering students (Rugarcia *et al*., 2000). These show that Woods has experiences in implementing and supporting programs that can develop engineering problem solving skills compared to other researchers that are not based on the engineering context. It is relevant to this study that is focused on developing rubrics as an assessment tool to assess electrical engineering students' problem solving process in project-based laboratories. The Woods *et al.* (1997) problem solving process have been referred and been used as a guideline in this research.

2.5 Project-based Learning

Project-based learning (PBL) is a student-centered learning strategy (Mills and Treagust, 2003) in which students are organized in groups and dealing with the project. The project given also based on challenging problems occurred that involves students to actively plan the solution and solve the problem in a group (Martínez *et al.* 2011; Mills and Treagust, 2003). Project is an activity that need a complete and functional outcome; usually this activity took a period of time and require work outside the normal period (Grant, 2002). There are variety of complexity of the project; however, all will related back to the theory or fundamental knowledge learned. Some project require short time to complete, but some project that relates to the real-life project took long time and include multidisciplinary work (Mills and Treagust, 2003). Particularly, PBL include the implementation phase where the students need to design some product and secondly, the analysis phase where the students have to identify the output or results obtain.

Project work is usually directed to the application of knowledge (Costa e*t al,.* 2007; Martínez *et al*., 2011). PBL usually motivate students to know more because the students can immedientiy see and apply the theory or knowledge learned into the real product or design (Martínez *et al*., 2011). This has been also agreed by Moursund (1998) and Grant (2002) that stated PBL can enable the diversity in learners in terms of interest or abilities because in PBL, learners shape their project according to their own ability.

In engineering education, PBL has widely implemented as an instructional teaching and learning strategy across subjects and course. Some of the engineering faculty which already implemented this T&L strategy were Martínez *et al*. (2011), Macías (2012), Hutchison (2016), Genis *et al.* (2007) and Kanigolla *et al. (*2014*)*. Martínez *et al.* (2011) has reported on how the PBL have improve their undergraduate students' learning for the topics of power supplies and photovoltaic electricity. A project has carried out for two topics and they used Moodle as the e-learning platform for assignment submission or as resources. The objective to adapt this PBL strategies into their class was to develop their students project planning skills and group management. Finally, the results reveal a positive effect of the PBL T&L strategy into their students. Surveys show that student have a very positive view of this course.

Instead of that, Kanigolla *et al.* (2014) has discussed the impact of PBL on their students' knowledge in Lean and Six Sigma course where included the theory and practical work. The uniqueness of this course is where the students were given a hands-on project and collaborate with the local companies. The students have been evaluted after the project completed. Based on the results shows, by including the PBL in the students' semester project courses, gave a positive impact in terms of students' knowledge in learning concepts. Instead of that, students were also able to apply the theory in solving real engineering problem. Besides classroom context, the PBL T&L strategy also been implemented in the laboratory setting. Macías (2012) has reported the positive impact of PBL in software engineering laboratory course. This appraoch was implemented with 56 undergraduates students and instructor. E-portfolio have been used in this study to assess the students' competencies.

Based on previous research have summarized the effectiveness of this PBL strategy in helping the educator to train and produce an excellent, critical and a good problem solver. Due to that, this study have select PBL as T&L strategy in engineering laboratory course as a case study to be studied.

2.6 Assessments

Assessments play a crucial role in students' learning nowadays. It should be seen as an important element that can enhance a learning process. As discussed in Chapter One, the history of assessments began since the mid-1980s when there were increasing demands from the people and higher education stakeholders to create "students' learning evidence" (Olds *et al.*, 2005; Shavelson *et al.*, 2007). Until now, in this 21^{st} century, assessments are still being updated and improved to achieve its objectives in reflecting students' achievements. In education, assessments can be one of the benchmarks in identifying the effectiveness of teaching approach to the students. One of the comprehensive definitions of assessment defined by University of Queensland, Australia in their assessments policy which have been reported by Joughin (2009) is:

> "Assessment means work (e.g. examination, assignment, practical, performances) that a student is required to complete for any one or combination of the following reasons: the fulfilment of the educational purposes, for provided basis for an official record of achievement and to permit grading of the student."
>
> (Joughin, 2009:14)

Based on this statement, it showed three important functions of assessment in education which are for educational purposes, students' records and grading. It means that assessments are also functioning as evidence that showed the weaknesses and the strengths of the educational process itself. During learning activities, students should try to understand and interpret new concepts being taught; and sometimes, students have to solve given problems or complete projects based on the knowledge they have. So, assessments can reflect whether the criteria that students have, to perform during a learning process are achieved. Besides that, assessments can also be defined as a judgment of students' achievements (Linn and Miller, 2005). It is an important tool that can identify how far students can understand the knowledge that they have obtained during learning session. Similarly, in engineering education contexts, assessments are known as a key that can improve the students' skills (Spurlin, 2006; Woods *et al.*, 2000). The normal trend nowadays that focuses on developing students' skills, compared to knowledge, requires effective assessments that truly reflect the students' progress. This trend is not only because of the shift happening in engineering education, but this is also a demand made by the industries that seek engineering graduates that have multidisciplinary skills.

Therefore, it is important to ensure alignment between learning targets, teaching and learning activities as well as assessment methods to enhance students' learning skills especially after they graduate (Biggs, 2006). It is important to highlight that students learn more when they know that their learning will be assessed rather than being told to learn the material only for the sake of acquiring knowledge. In this case, assessments should match with the instructional objectives so that students' performance and learning skills can be judged whether they reach the requirements of the instructional programme.

2.6.1 Types of Assessments

There are two types of assessments that have always been discussed by researchers nowadays which are formative and summative (Moreno, 2010; Rust, 2002; Orlich *et al,*. 2012; Fisher *et al.,* 2008). Both these types of assessments are different in terms of the time applied and its objectives. Formative assessments can be described as an assessment that gives the information about students while the learning process and the instructional process are still on-going (Moreno, 2010; Hanna and Dettmer, 2004; Orlich *et al.,* 2012; Fisher *et al.,* 2008). Usually, the formative assessment is applied during the teaching and learning process. Formative assessments are the assessments that provide information to lecturers and students while teaching and learning activities are on-going. Lecturers may pose questions to students during the learning activities; and this method helps lecturers to identify whether the objective of that activity is achieved without having to wait until the final class. Apart from that, by using this type of assessment, students can immediately determine the part of the learning process that they do not understand and are weak in. Examples of this assessment method are classroom quizzes, pre-tests or pre-instruction assessments, which help lecturers to identify the level of students' understanding; through this method, lecturers can observe students' skills during learning activities.

Another type of assessment used is the summative assessment. Summative assessment is different with the formative assessment in terms of its function and the time given. Summative assessments provide information about students' performance at the end of an instruction period, and this method is typically used for grade assignments (Moreno, 2010; Fisher and Frey, 2007). Normally, this assessment is to sum up a student's entire accumulation of knowledge or achievements at the end of an instruction period; the purpose is to provide lecturers or students with information about how far the students have progressed in learning. Some examples of this kind of assessment are final year tests, end-of-year performances and final project assessments.

However, although both formative and summative assessments are different, in the students' perspectives, both assessments help them in identifying their levels of understanding (Orlich *et al.*, 2012). Because of that, for this research, Problem solving Process Rubrics (PPR) as a formative assessment tool for assessing problem solving skills in the PB Lab course have been developed. The formative assessments have been chosen to be designed in this study due to its' characteristics that is more focused on the process of learning compared to determining the students' final grade. In assessing problem solving process in this study, the step-by-step process that the students go through must be assessed so that the steps that the students' weakness in solving problems can be determined and improved. Rubrics is one of the performance assessments that is categorised under formative assessments. As such, this research attempts to develop a rubric that can assess students' problem solving skills in the PB Lab course; the aim is to define the levels of students' capabilities in solving real-world problems and completing real-life projects given.

2.6.1.1 Performance Assessment

Performance assessment is a formative assessment that requires students to use their knowledge and skills to complete the task (Moreno, 2010). According to Wren (2009) reported American Educational Research Association, American Psychological Association and National Council on Measurement in Education (1999) has defined performance assessment as "product-and-behaviour" measurements that relate with the real-life context or condition. It is an assessment that allow the students to come out and construct their own respond or solution (Darling-hammond *et al.,* 2010).

In contrast to the traditional assessment such as multiple-choice testing, quizes and so on, performance assessment give change to students to create answer or produce product rather than choosing the right answer out of a list provided by educator. This will automatically enhance students' critical thinking skills and problem solving skills required especially in this 21^{st} century (Wren, 2009). Instead of that, performance assessment are believed to be more accurate and effective assessment method rather than examination due to its characteristic; assessing the process of students' learning and not only focusing on the outcomes (Miller and Linn 2000). To conclude, it shows that there are three criteria related to this assessment is such as ; (a) assessing learning process, not the product or output; (b) require students to perform and demonstrate their competencies and lastly (c) it relates more to real-life context.

In engineering education context, performance assessment have been implemented widely in assessing students especially in product or project-based such as Wadhwa *et al.* (2015),Bailey and Szabo (2006) and many more. However, thereare some limitation in performance assessments which is in terms of it reliability (Shavelson *et al.,* 1992). It is advisable to develop and design rubric assessment tools to overcome this issues (Moreno, 2010; Stiggins, 2005). By using rubrics to assess performance, the validity and reliability of the performance assessment was highly improved. This have been agreed by many researchers in engineering domain that used rubrics to assess their students' performances. (Wolf and Stevens, 2007; Baharom *et al*., 2013).

2.6.2 Validity of Assessments

Assessment is a mechanism that can enhance students' learning far more than most educators know. It gives much more positive impact towards students' learning and nowadays, assessments are not only used as a supporting document in education, it also becomes one of the important elements in constructive alignment (Biggs, 1996). Thus, the development of assessment tools in enhancing students' learning must be reviewed and validate so that it truly reflects the students' achievements. There are several important characteristics of the assessments that must be emphasized. In this study, the validity of the assessments tools will also be focused on. Validity is a crucial factor in the selection and application of an assessment. Although some of the studies highlighted thoroughly the reliability aspects of the assessments, but according to Akib and Najib (2015) and Margaret and Lynn (2006), the validity aspect should be focused on more. If the assessments have high reliability values, it does not reflect that the assessments also have high validity aspects (Margaret and Lynn, 2006).

An assessment is valid when it can measure the skills or knowledge listed in learning outcomes and assign accurate scores to the measurements (McMillan, 2007). In addition, the validity of the assessment itself depends on its alignment with the learning objectives and leaning activities used to promote students' learning performances and skills. There are two types of validity aspects which are most stressed by many studies such as content and construct validity (Hersen, 2004; Moskal and Leydens, 2014). Both of these validity aspects have also been reviewed in this study. Content validity represents the extent the assessments measure what it was designed to assess, to reflect the required students' outcomes (Jonsson and Svingby, 2007). The questions such as "how well the items assess the desired content?" has always been asked to review the content validity aspect. Several studies such as from Hersen (2004) suggested several ways in determining these validity aspects such as by experts' review and test blue print. Instead of that, Akib and Najib (2015) in their research also highlighted the validity of the Assessment of Learning that they developed in University of Muhammadiyah Makassar, Sulawesi. In order to make sure their assessment instrument valid, the construct of the items have been developed properly by using these methods; (a) metadata analysis; (b) expert validation; (c) pilot test and (c) data analysis using Rasch model.Hence, the study shows the implementation of the Rasch model can help in determining the final validity of the instrument. Table of specification (TOS) also recommended by experts in validating the classroom assessment. TOS is a table that includes a lists of the learning objectives and different level of understanding that need to be assessed (Moreno, 2010). Gronlund (2000) also reported the effect regarding this TOS table in his previous research.

In the context of this study, the experts who have experiences in Project-based Laboratory (PB Lab) course and its' problem crafting was selected to review the PPR design. Although the validation aspect in this study took several cycles before it was validated, the final results of the PPR design was successfully agreed by all the participated experts.

Just as content validity, construct validity is also one of important aspects in validating the instruments of assessments. It represents how well the items listed in the assessments assess particular skills or content knowledge. Usually, the validation of the construct is done after the content validation process. Besides, according to Weiner (2003) verifying the construct validity of assessments was also considered as an on-going process of collecting evidence for the assessment. It is due to the function of construct validation itself which examines the accuracy of the items in the assessments' outcomes needed by the course. Thus, by collecting and analysing the assessments results, it shows and presents the true results of students' outcomes and their levels of achievement. Content representativeness and dependability of measurement are important aspects of these types of validity (Bell and McCallum, 2008).

Thus, the development of Problem solving Process Rubrics (PPR) in assessing students' problem solving skills in this study are reviewed in terms of its validity elements. In validating its' construct and contents, there are experts' review and the meta data analysis are also done in triangulating results from various data collections that is relevant for the PPR design. Although most of the analysis have been done using the qualitative approach, the results was already reviewed and validated starting at Phase I of this study. Moreover, it is important to highlight that if the validity of the rubrics design was worth and does not truly assess the outcomes needed, the results of students would also not truly display their true skills or progress. So, the validity of the PPR design in this study is thoroughly reviewed.

2.7 Assessments of Problem solving

Based on literature reviews, many studies show that various assessments tools have been developed in assessing students' problem solving skills. However, until now, according to Docktor and Heller (2009) there are still no standard ways to measure these skills. One of the method in assessing problem solving skills done by Mourtos *et al*. (2004) was by using open-ended problem. This problem has been assigned to a few teams and each of the teams must solve the problem in the time given. Marks will be given based on the proposed solution. However, the most interesting part in this Mourtos *et al.* (2004) study was when they implemented and taught their students the step-by-step process of solving problem by Wood *et al.* (1997). Based on the results, it showed that most of the students got better marks when they have been taught the steps of problem solving. It can be summarized that in assessing students' problem solving skills, especially by using an open-ended problem, the process that the students go through must be facilitated and monitored to ensure that they understand the issues of the problem.

The School of Medicine in the University of New Mexico has developed an online examination tool which can be implemented as formative and summative assessments for individual students in large classes (Anderson *et al.,* 2011). This online tool, known as Individual Problem solving Assessment (IPSA), is a tool which evaluates a student's ability to apply content knowledge to solve problems. IPSA are given to students electronically as progressive-reveal essay exams, which are based on real-world situations. Based on the outcomes received, it is proven that this tool can promote learners' skill in transferring conceptual knowledge to solve problems. Besides, another research done by Tan discussed about the benefits of self and peer assessments in assessing problem solving skills especially in the Problem Based Learning (PBL) context. Self and peer assessments are one of the effective assessment strategies because the students take responsibilities for their own learning and continuous personal development. Besides that, in assessing problem solving skills using this kind of assessment, students can reflect back on their process in solving problems and they would understand more. However, until now the limitation and effectiveness of these assessment tools are still being questioned although most of the researchers claimed that these kinds of assessment can be subjective and hard to measure (Tan, 2004).

On the other hand, a study done by Chow *et al.* (2012) also discussed about the assessment of problem solving skills. This study introduced the assessment plans that have been developed by the School of Engineering at the Hong Kong University of Science and Technology to gather evidence of students. Rubric has been chosen as an assessment tool in this study. According to Chow *et al.* (2012), rubric was a suitable assessment tool to assess the capstone course. It has the criteria and the levels of students' performances that help the lecturers to assess more objectives and the graduates' competencies. But, in developing a good and practical rubric, the rubric itself must be carefully constructed so that the marks given truly reflect the students' performances. In this study, the rubrics have been designed with five levels, which are Exemplary (level 5-4), Average (level 3) and Needs Work (level 1). Besides that, scoring rubrics have also been implemented in Structural Engineering Instrumentation and Measurements Laboratory of Department of Civil and Environment at University of Rhode Island, in assessing their students' problem solving skills (Gindy, 2006). In this study, the rubric has been designed and implemented to evaluate the students in design experiments. This 0-to-3 scale rubric has been tested by Rutgers Physics and Astronomy Education Research (PAER) to verify its validity and reliability. The design of this rubric showed that it is more suitable for evaluating the process of how students design experiments, rather than the outcomes.

Besides that, in the mathematical course, problem solving is one of the skills assessed. According to Egodawatte (2010), to enhance a student's learning, especially in mathematical subjects, a rubric for self-assessment and peer assessment of mathematical solving task has been developed. The main objective in designing this rubric is to promote rubric as a learning tool to students. This rubric contains 5 levels of performance and the criteria of assessment in this rubric are based on the components of the mathematics task itself. Also, based on the literature studies it can be seen that most studies, whether it is from various contexts such as education contexts, engineering contexts, mathematician contexts and so on, choose rubrics to help the educators to assess the students' problem solving skill, for example Chow *et al*., (2012), Hong Kong Centre of Teaching and Learning (2010) and Docktor and Heller (2009). These show that rubrics were one of the assessment tools that were mostly preferred by many researchers in assessing their students.

In Malaysia, problem solving skills are also one of the outcomes that have thoroughly been assessed and focused on among educators. Recently, there are a number of researches that are focused on developing suitable assessment tools to measure students' problem solving in Malaysia. However, according to Nair and Ngang (2010), it is still very limited.

One of the study done by Xiao-lian and Chan (2007) showed the effect of authentic assessments in assessing problem solving skills in problem-based learning (PBL) environment. As known, students' problem solving skills are one of the outcomes that are mostly needed in PBL. The elements in PBL that uses real world problems and tasks helped to enhance students' problem solving skills. In this study, the authentic assessments that have been used were self-reflection, peer evaluations and task completion report. Authentic assessments are types of assessments that do much more then assess the students' learning progress compared to traditional assessments such as standardize test that only assess students' skill in recalling the factual content knowledge (Ward and Lee, 2002; Herrington and Heriington, 1998). Based on the conclusion obtained, it is reported that these authentic assessment strategies benefit the students. Through these kinds of assessments, students' problem solving skills can thoroughly be assessed and analysed. Although there are some students that do not achieve the skills required successfully, but through these assessments, students can identify their mistakes and not repeat them again in the future.

The work done by Xiao-lian and Chan (2007) was the same with the research done by Mohd *et al.* (2005). Mohd *et al.* (2005) is another Malaysian researcher who implemented Cooperative Problem-Based Learning (CPBL) approach in her classroom. This CPBL approach aims to enhance students' learning and thinking skills especially in problem solving. Due to that, several assessments have been conducted in this class such as the final examination consisting of a final problem and a written examination. In answering the final problem obtained, students need to find out the information based on their industrial visit because most of the problems come from real industrial problems. Besides that, Mohd e*t al.*(2005) also stated that the written examination also matched the cognitive taxonomy level of the outcomes. The written test has also been implemented to motivate students to think about the solution and this suits the requirement of the Malaysian Engineering Accreditation Council.

In addition, another work done by Syed *et al*. (2011) also focuses on development of an instrument to assess the engineering students' ability to solve problems while undergoing cooperative problem-based learning (CPBL) in engineering classrooms. The instrument which is known as Engineering Problem solving Instrument (EPSI) has been developed using the Philip's flowchart of problem solving model which consists of definition, strategy and solution phases.

Besides that, the Hmelo's component of problem solving assets has also been referred especially in terms of knowledge, perception and cognitive processing. Based on the study, it showed that the researcher did some literature reviews regarding the essentials related to engineering problem solving. Then, the suitable concepts were summarized from other studies and further extracted to form the EPSI. However, the suitable concepts that have been chosen must suit the CPBL goals. Then, the Philip's flowchart elements and Hmelo's assets are taken into consideration in designing the EPSI's construct. There are five main constructs that was focused on in EPSI, such as problem identification, problem analysis and synthesis, solution generation, self-directed learning and reflection. In designing the scale of the EPSI, the researcher has used 6 scale of Likert scale (from 0 to 5) which "0" stands for "not at all of me" and "5" is "very true of me". And finally, based on the pilot study, this EPSI showed the enhancement of students' problem solving skills by improving the students' deep learning in this CPBL course.

Next, Rosli *et al*. (2013) in her work have examined students' ability to solve problems especially in the mathematical context. She and her research team have selected one of the authentic assessments which are having performance rubrics to examine students' ability to solve mathematical problems. According to Van de Welle *et al.* (2009), performance rubrics is one of the suitable tools that break the use of traditional assessments which only focuses on correctness of the results students obtained. Besides that, if the rubrics have been designed well according to the program outcomes, it can successfully assess students' progress. In this study, Rosli *et al.* (2013) has implemented five open-ended tasks that have multiple strategies to assess students' understanding through problem solving, and rubrics have been chosen as an assessment tool in this study. The design of the rubric was adapted from Charles *et al. (1987)*. This rubric has 0 to 4 points of students' conceptual understanding criteria. However, based on the results obtained, it showed that most of the teachers in this study were not really interested with the rubrics. Majority of them were much more satisfied with traditional tests because they believed that they do not have sufficient time to implement authentic assessments like rubrics in the classroom.

As a conclusion, based on the several methods of problem solving assessments presented above, many studies and researches have been done to design suitable tools to evaluate students' problem solving skills. However, there are no standard ways to assess the problem solving skills especially for engineering laboratory courses. In addition, based on the discussion above, it can be seen that most of the problem solving assessments are more focused on assessing the final outcomes or the results correctness rather than determine the weaknesses and the ability of the students to solve the problem when they go through the process (Schoefeld,1985; Docktor and Heller, 2009). Instead of that, although the problem solving assessment implemented by Syed *et al*. (2011) and Chow *et al.* (2012); which is rubrics have been designed and suitable for engineering context, but the rubrics was not align with the instructional teaching and learning method implemented in this study which is project-based in laboratory. Both of the rubrics was suitable for CPBL and for civil engineering context.

Due to that, this research aims to develop a new Problem solving Process Rubrics (PPR) as a formative assessment that can assess students' problem solving skills in electrical engineering laboratory especially in the context of Project-based Laboratory (PB Lab) course.

2.8 Rubrics

According to Stiggins (2005), Arter and Chappuis (2007) and Moreno (2010), rubrics are defined as a scoring tool that describes the criteria for grading students, especially for subjective assessments such as students' performance, attitudes, problem solving skills and other subjective assessments that cannot be rated by number. Besides, Stevens and Levi (2005) also stated that rubrics are an assessment tool that list specific expectations for certain assessments developed. It divides assessments into several parts of components, and it also provides a specific description of the levels of performance required for each of those parts. By using rubrics, students can understand and know the criteria measured by lecturers when the learning process starts. Besides, rubrics guide students to identify goals they should accomplish and help them determine the strengths and weaknesses of their products and performances. This will enable students to focus on the criteria being assessed during the learning activities. In addition, rubrics are also good assessment tools that can help lecturers in defining complex learning objectives and forming proper judgments about students' work (Arter and Chappuis, 2007). There are two types of rubrics that have been practiced recently, such as holistic and analytic (for rubric's score), and general and task-specific (for criteria). Table 2.2 shows the summarisation of description for each types of rubrics based on Stevens and Levi (2005), Arter and Chappuis (2007) and Nitko (1996).

Table 2.2: Types of rubrics

RUBRIC'S PART	TYPES OF RUBRICS	DESCRIPTIONS
Rubric's Score / Rate	Holistic	• Provides a single rate or scale-based rate on an oversall impression of students' products or students' performances.
	Analytic	• Provides rate or score separately based on parts or characteristics of students' products or students' performance, and then sum these part scores to obtain a total score.
Rubric's Criteria	General	• Contains criteria that are general across tasks.
	Task specific	• Contains criteria that are specific for certain tasks.

Based on Table 2.2, two types of rubrics can be considered in designing rubrics for applications: (i) analytical rubrics, which are specific for certain tasks; or (ii) holistic rubrics, which are general across all tasks. The designs of rubrics are dependent on what educators are trying to assess and the purpose of giving the assessments (Airasian, 2000).

Importantly, to design a good rubric, several contents of the rubric should be considered. Wiggins (1998) opines that a typical rubric contains a possible scale or level of performance, criteria of performance, and the descriptor of each level of performance. Besides that, Stevens and Levi (2005), in their book entitled "Introduction of Rubrics" also discussed that rubrics are composed of four basic parts: a task description (the assessment), a scale of some sort of level of achievement or performance, the dimension of the assessment (a specific skill or knowledge involved in the assessments) and lastly, a description of what constitutes each level of performance. Apart from that, Arter and Chappuis (2007) also have summarised a good rubric design proposed by several researchers such as Johnson (1996) and Popham (2002), which contains the following: appropriate criteria of products or skills being assessed, well-organised descriptors as well as clear and appropriate levels of rubrics. To be clear, an example of a basic rubric's format is as follows:

Table 2.3: Basic rubric format

Rubric's Criteria	**Rubric's Levels**			
	Level 1	Level 2	Level 3	Level 4
Criteria 1	Descriptor 1	Descriptor 2	Descriptor 3	Descriptor 4
Criteria 2	Descriptor 1	Descriptor 2	Descriptor 3	Descriptor 4

Table 2.3 illustrates the basic format of rubrics suggested by most researchers (Johnson, 1996; Popham, 2002; Arter and Chappuis, 2007). There are 4 basic parts of rubric design that should be emphasised: rubric's criteria, levels, and the descriptors of criteria under each level. For the part of rubric's criteria, usually the number of criteria is based on learning targets lecturers want to refer to when evaluating students' works or performances (Arter and Chappuis, 2007). It is important to identify the correct criteria that should be incorporated in the rubrics so that they can be aligned with the learning objectives. Right criteria are helpful to students to determine the quality of their works or performances. In addition, according to Arther and McTighe (2000) the criteria listed in the rubrics must meet the students' performance listed in outcomes. This is to make sure that the alignment

between the outcomes, teaching and learning activities match the assessments' design. Normally, the criteria of the students will be obtained based on students' work and through observation during the class activities. In this research, the criteria of problem solving listed in Problem solving Process Rubrics (PPR) was already aligned with the Engineering Accreditation Council (EAC) and Project-based Laboratory (PB Lab) outcomes.

Besides that, to ensure the validity and reliability of rubrics, proper descriptors should also be formulated based on a specific criterion (Arter and Chappius, 2007). It is important to state the right descriptor under each level of rubrics to have a clear view on "what does each level mean". In other words, the descriptor for each level contains criteria or standards by which the work or performance will be judged. Basically, indicators are often used as descriptors to provide examples of signs of work and performance. Lastly, another part of the rubric's format which is really important in assessing students' work is the rubric's levels. There are several types of rubric levels that can be used nowadays. Some of them are divided based on "numbering scales", (e.g. scale 1-5) and some are based on "word", which indicates level of performance, (e.g. Less Good, Good, Excellent) (Zimmaro, 2007). The scales describe the quality levels of the tasks that have been performed by students (Stevens and Levi, 2005). In addition, to ensure the reliability of the rubric's design, rubric's levels in the form of "word" scale such as "competent, medium and not yet competent", must be clear and can be understood by the evaluator who uses the rubrics. There is no fixed formula for the numbers on a rubric scale. However, it is important to understand the implications as stressed by Stevens and Levi (2005), "the more the levels of rubrics, the more difficult it is to differentiate the grading.". Previous research also shows the rubric assessment have widely been implemented in engineering courses (Ralston, 2010; Cancela *et al,.* 2016; Azli *et al,.* 2012; Saunders *et al.*, 2003) and many more. Most of the researches have used the rubrics due to its effectiveness in helping them to assess students especially in active-learning course. Besides benefiting the lecturers, the rubrics also helped the students to understand course-specific learning outcomes e.g. problem-based learning (Ralston, 2010).

So, based on the above discussions, this research has selected to design a Problem solving Process Rubric, known as PPR that focuses on assessing students' problem solving skills; this is one of the criteria listed in the PB Lab programme outcomes and is required by EAC. Further details on the process of rubric development are discussed below.

2.8.1 Process of Rubrics Development

As discussed above, there are three important elements in rubrics' design which are the criteria, level of students' performances and the descriptors. In designing all of the three elements, the researcher has reviewed several step-by-step processes of rubric development proposed by many researchers. Some of the researchers were Arter and Chappuis (2007), Andrade (2014) ,Yoshina and Harada (2007) and Mertler (2001). All of the processes have thoroughly been reviewed by the researcher and finally the Mertler (2001) rubrics development process was chosen. Table 2.4 shows the differences of each rubrics development process which have been reviewed.

Table 2.4: Studies on the Process of Rubric Development

Step-by-step process of rubrics development	**Arter and Chappuis (2007)**	**Violet H. and Joan M. Yoshina (2005)**	**Andrade (2014)**	**Mertler (2001)**
Re-examine the learning objectives to be addressed.	/			/
Identify specific observable attributes (that you want to see and those you don't want to see) your students demostrate in their products, processes or performances.	/	/	/	/
Brainstrom characteristics that describe the attributes.	/	/	/	/
Write through narrative descriptions for excellent work and poor work for each attributes.	/	/	/	/

Complete the rubric by describing other levels on the continuum that range from excellent to poor for each attributes.	/	/		/
Collect sample of students' work that exemplifies each level.	/			/
Test and Revise rubrics .	/	/	/	/

Table 2.4 shows the differences between each model of problem solving processes. Although there are many step-by-step process proposed nowadays, the Mertler's rubrics development process have been selected to be a guideline in this study due to its process which are compiled from various sources such as Airasian (2000 and 2001) and Nitko (2001). Besides that, based on literature reviews, it showed that Mertlers' rubrics development process has also been widely used and referred by many researchers in designing their classroom rubrics such as Martínez *et al.* (2011) and Oakleaf (2009).

In this study, Mertler's rubrics development process was referred by the researcher as a guideline in designing the Problem solving Process Rubrics (PPR) for the Project-based Laboratory (PB Lab) course. As shown above, the rubrics development process proposed by Mertler (2001) starts with selecting the main learning objectives to be addressed. So, in this study, the main outcomes or objectives which are focused on are problem solving skills. Observation and some interview sessions have been done in several PB Lab laboratories and this helped the researcher in selecting the criteria and brainstorms the rubrics' descriptors. The detailed process in developing the PPR design with a guide from Mertler (2001) process would be discussed in Chapter 4.

2.9 Conclusion

This chapter have been divided into several parts. Firstly, the definitions of problem solving and several models of problem solving skills have been reviewed in this chapter including the Woods *et al*. (1997) Problem solving Process. Then, the learning theory relevant to this study which is the Constructivism Theory was also discussed. Besides that, there are also some discussions on types of assessment methods and several examples of assessment methods used in various universities for assessing students' problem solving skills. Finally, since this project focuses on the development of the rubrics, a comprehensive overview of the rubrics and Mertler's Rubrics Development Process has also been included.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

Research methodology refers to the systematic way data is collected and analysed in a research. According to Henning (2004) “methodology” can be defined as the process of gathering and analysing data in order to identify their relationship with one another. This procedure is done to obtain findings that answer the research questions and achieve the research objectives. Besides that, through the proper data collection and analysis process planned by the researcher, the validity of the findings can be maintained (Conrad and Serlin, 2006).This chapter will specifically discuss in detail the methodologies used in this research. The discussions are arranged according to the following order:

i. Research design
ii. Research framework
iii. Research operational framework
iv. Research samples and setting
v. Data collection methods
vi. Data analysis technique
vii. Quality of the qualitative data
viii. Validity of the rubrics design
ix. Conclusion

3.2 Research Design

Research design is the type or the strategy of inquiry which leads the researcher to a clear direction of procedures during an educational research (Creswell, 2007; Denzin and Lincoln, 2011). Research design can also be summarised as a specific set of procedures to represent the data collection, data analysis, and the report-writing methods (Creswell, 2003). Generally, a proper research design is crucial to answer the research questions clearly.

In this study, the qualitative case study research design was selected by the researcher to achieve the objectives of this study. According to Merseth (1994), "cases" are the reflection of real-life situations; they represent good and bad practices, failures, as well as successes of the cases. Besides that, the facts of the cases must not be changed in order to expose how the situation should be handled (Kardos and Smith, 1979). According to Yin (1994), a case study is "an empirical enquiry that investigates a real-life phenomenon and this context is not clearly evident and it relies on multiple sources of evidence". The variables involved in this kind of research are not controlled or manipulated. The focus of this type of research is an in-depth investigation of a predefined phenomenon and its context (Cavaye ,1996; Yin, 1994). It focuses more on the nature of the real-case, including its history, economic, or political context, setting and other subjects that can represent the uniqueness of the case itself.

Applying this description, this study has implemented qualitative case study in order to gain in-depth understanding of the assessment of problem solving in the project-based learning in the laboratory context. Thus, the case study was carried out at a project-based learning laboratory known as the Project-based Laboratory (PB Lab) course in the Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM). The main participants of this study was the PB Lab facilitator's who conduct and facilitate the students in the PB Lab course. This active-learning lab has been implemented since 2007 after it was proposed by the 4^{th} Year Laboratory Coordinator in 2003. The implementation of the PB Lab course was to align with the

Engineering Accreditation Council's (EAC) requirements, as well as to keep in line with the demands of the industries (Azli *et al*., 2012). In addition, this lab is compulsory for all Electrical Engineering final-year students, where they are divided into groups of 3 to 4. The variety of real-life problems carried out throughout the course is what makes the PB Lab unique and each problem must be solved by the students in their respective groups within 4 weeks (a month). Some problems require the students to use either software or hardware tools, while some problems require them to use both. The open-ended problem given in the PB Lab course provides a space for students to develop their problem solving skills, as well as decision-making before they graduate. The effectiveness of the implementation of this course across several electrical program was been proved by Azli *et al*., (2012) with the positive feedback from the students. Furthermore, all the outcomes of the PB Lab course including problem solving skills was been assessed using the rubrics assessment tools designed by PB Lab Task Force members since 2007. This is the challenging phase and the uniqueness of the PB Lab courses where the development of an assessment tools must be not only can assess the students' performances across several electrical programs but also across several types of real-life problems which can be solve whether by using software, hardware tools, or both.

Based on the preliminary study done by Bahri *et al.* (2012) identified there are issues occurred in terms of the assessments of the PB Lab itself in assessing problem solving skills. Specifically, the issues are; (a) Method in assessing problem solving criteria and (b) The misallignment of the assessment's objective for problem solving skills. Due to that, the development of appropriate problem solving assessments tools named Problem solving Process Rubrics (PPR) were selected to be develop in this study and the outcomes of students' problem solving skills have been selected to be focus on. Therefore, the objectives of this research is to:

a. To identify the problem solving process that occurred in the PB Lab course to be included in designing the PPR.

b. To construct the rubrics' criteria, descriptors and levels of performances which relate to problem solving process that occurred in the PB Lab course to be included in the PPR design.
c. To examine the validity of the PPR designs including the contents and constructs in assessing problem solving skills for PB Lab course.

The details about the PB Lab course as the actual case studied in this research are discussed below.

3.2.1 Project-based Laboratory (PB Lab) Course

The Degree in Electrical Engineering four-year programme at the Faculty of Engineering (Electrical) (FKE), Universiti Teknologi Malaysia (UTM) requires students to register in at least one undergraduate laboratory course each year. For this reason, the 4th Year Undergraduate Laboratory is conducted for the 4th-year first semester students for 12 weeks. This laboratory course previously used the conventional instruction-based laboratory approach, which is teacher-centred. In this conventional laboratory approach, each step of the procedure is guided by specific instructions; the students only need to follow the instructions strictly with very little understanding.

Realising the disadvantage, a non-traditional laboratory approach, otherwise known as Project-based Laboratory (PB Lab), was introduced in the FKE in 2007, replacing the previous 4th Year conventional laboratory approach. According to Azli (2005) the decision to replace the previous traditional laboratory approach with the more non-traditional laboratory approach was based on several reasons. The main reason is the need to fulfil the requirements as stated in the Engineering Accreditation Council (EAC) Manual 2003. The requirements for the laboratory work stated that "For a 14-week semester (not including examination or mid-term break), one credit hour is defined as: two hours per week of laboratory or workshop".

Based on the above requirement, the laboratory must be conducted for 2 hours per week and for the 14 weeks in a semester in order for the laboratory to be eligible as a one-credit-hour course. However, in FKE, the 4th Year Laboratory has to be held in a two-credit-hour course per week to contribute to the curriculum of the Bachelor of Engineering (Electrical) programme. Apart from that, because the 4th Year Laboratory in FKE is conducted for a duration of 12 weeks only, the lab has to be conducted for a maximum of five hours per week within the 12 weeks of a semester to make sure this two-credit-hour 4th Year Laboratory course aligns with the above EAC requirements. In conducting the previous conventional laboratory course, the time allocated to the students to carry out experiments in the laboratory was only 3 hours per week for the 12 weeks of a semester. This, however, did not fulfil the EAC requirements (Azli, 2005). Another factor that prompted the switch from conventional laboratory approach to the project-based approach in the PB Lab course was to expose the undergraduate final-year students to real-world problems and projects. With realistic exposures, the students will be ready to enter the job market in the field of electrical engineering after they graduate from the course

3.2.1.1 PB Lab Program and Course Outcomes

As mentioned earlier in Chapter 1, the outcome-based education (OBE) approach has been listed as one of the requirements of EAC and implemented in UTM since 2004. According to Nicholson (2011), OBE is a student-centered approach in education narrows down the required learning outcome, as it focuses more on the outcomes in preparing graduates for a professional practice (MOHE, 2006). This clarifies that, in order to design instructional programmes, the question of "what is the students' capability at the end of this programme?" has to focus more on the aspects of the curriculum, instruction, and assessment methods that will truly and achieve the necessary outcomes of the future engineer. Realising that the outcome is one of the important things that will be evaluated, Faculty of Engineering (Electrical) has taken conditional steps to determine the required outcomes for each of the programmes and courses conducted. Table 3.1 shows the programme outcomes (Azli, Tan and Ramli, 2010) as listed by the faculty:

Table 3.1: PB Lab Programme Outcomes

Programme Outcomes (PO)	Outcomes
PO1	Ability to apply knowledge of mathematics, sciences and electrical engineering to the solution of complex engineering problems.
PO2	Ability to conduct experiments, perform analysis and interpret data for complex engineering
PO3	Ability to identify, formulate, investigate and synthesis of information to solve complex engineering problems.
PO4	Ability to use appropriate techniques, skills and modern engineering tools, instrumentation, software and hardware necessary for complex engineering practice with an understanding of their limitations.
PO5	Ability to design solutions for complex system, component, or process within a defined specification that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.
PO6	Ability to articulate ideas, communicate effectively, in writing and verbally, on complex engineering activities with the engineering community and with society at large.
PO7	Ability to function effectively as an individual, and as a member or leader in diverse teams.
PO8	Ability to recognise the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.
PO9	Ability to analyse the impact of global and contemporary issues, the role of engineers on society, including, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering.
PO10	Ability to understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development
PO11	Ability to execute responsibility professionally and ethically.
PO12	Ability to demonstrate knowledge and understanding of engineering and management principles to manage projects in multidisciplinary environments.

Table 3.1 shows the twelve programme outcomes (POs) for the programmes under FKE. They included the SKEE (Electrical), SKEL (Electrical-Electronic), and SKET (Electrical-Telecommunication) reviewed in this study. According to the list of POs, problem solving skill is one of the more prominent skills that a student should possess by the end of their programme at FKE. Program Outcomes such as

PO1 and PO3 clearly stated the need for the students to solve complex engineering problems. As a result, one of the courses that has been identified as the key factor in developing the students' problem solving skill is the 4th Year Laboratory, or the PB Lab course, which was investigated in this research. The PB Lab has five course outcomes (Azli, Tan and Ramli, 2010) :

Table 3.2: PB Lab Course Outcomes

Course Outcomes (CO)	Outcomes
CO1	Identify, formulate, investigate and synthesize information to solve complex engineering problems independently by relating theories and concepts discussed in lectures and information obtained from other learning resources.
CO2	Use appropriate techniques, skills, modern engineering tools, instrumentation, software and hardware necessary for solving complex engineering problems with an understanding of their limitations.
CO3	Conduct experiments and research, perform analysis and interpret data for complex engineering problems.
CO4	Plan and conduct a project within a specified budget and time frame using available resources for complex engineering problems.
CO5	Design solutions for complex systems, components, or processes with appropriate consideration for public health and safety, legal and cultural issues, and environmental consideration
CO6	Function effectively as an individual, and as a member or leader, in diverse teams.

Based on the PB Lab course outcomes listed above, problem solving skills is again among the more prominent skill that is crucial for a student to possess by the end of the course. PB Lab course outcomes (CO), CO1 and CO2, clearly stated a criterion of problem solving skills, whereby Students must be able to "identify, formulate, investigate, and synthesize information to solve complex engineering problems independently by relating theories and concepts discussed in lectures and information obtained from other learning resources", as well as to "use appropriate techniques, skills, modern engineering tools, instrumentation, software, and hardware necessary for solving complex engineering problems with an understanding of their limitations". Both of these PB Lab course outcomes are related to problem solving skills, as they stress the need for the students to be able to solve complex engineering problems using their existing knowledge and practical skills. These outcomes are aligned with the outcomes of the Engineering Accreditation Council (EAC) numbers two and three, which require students to have complex problem solving skills.

3.2.1.2 PB Lab Activities

Project-based Laboratory (PB Lab) is a 4th Year Laboratory course that applies a “complex problem or project” as an approach to develop students’ thinking and practical skills in a laboratory setting. With its successful implementation is an active participation of the students compared to the previous conventional lab format. It is conducted during the first semester of the fourth-year on undergraduate Electrical Engineering students and aims to induce change in the teacher-centred mode to a student-centred learning approach through the introduction of a real-world problems in group projects. Previously, the 4^{th} Year Laboratory course was conducted using the conventional way, where the students were required to solve problems by directly following the procedures of the experiments provided.

Unlike the previous conventional laboratory, PB Lab requires students to develop their own procedures by relating their prior knowledge to solve the problem or project given. Based on the student cohort (Azli, 2005), the PB Lab was highlighted as an appropriate course that encouraged students to be good team players and creative problem-solvers in the workplace environment. This is due to the structure of PB Lab course that exposes students to situations that require their problem solving skills in a team. There are several laboratories at FKE that implemented the “PB Lab” approach. However, in this research, only the laboratories of SKEE (Electrical), SKEL (Electrical-Electronic) and SKET (Electrical-Telecommunication) programmes were discussed. Students are required to complete one problem or project for each lab in the period of 4 weeks, which means 12 weeks are intended for 3 problems or projects. Furthermore, the time allocated for the PB Lab course is 3 hours per week (with a total of 36 hours) in-lab session with facilitation from a PB Lab facilitator and 2 hours per week (with a total of 24 hours) out-lab session outside of the laboratory time. Students are divided into groups of 3 to 4 members each and given the task to solve 3 problems or projects by conducting experiments or simulation for 4 weeks.

Projects that the students are required to solve are designed by experts. In this case, these experts are experienced lecturers. Based on the given project, students brainstorm for ideas, engage in discussions, and express their opinions on the probable solutions to the problem at hand. This is considered a challenging learning process for the students, as they have to develop a deep understanding of the subject matter in order to establish suitable methods that can be applied to solve the problem. To accelerate this process, a *Student Pack* is made available for each given project (Azli, 2012). It consists of relevant materials that assists the students in solving the project's problems. They download the *Student Pack* from the respective laboratory's website after they have presented the results of their preliminary discussion to the facilitator-in-charge. In addition, the *Facilitator Pack* (Azli *et al*., 2012) is prepared for each project and given to the PB Lab facilitators who are in charge of the lab. This is necessary, as not all project designers are the facilitators. Thus, the *Facilitator Pack* is a tool that describes the probable solution or the details of the project in which the facilitators can refer to.

Therefore, to gain more understanding of the PB Lab learning activities, Table 3.3 shows the process of solving PB Lab problems, starting from the first week until the fourth, and last, week. To enhance the students' problem solving skills during the PB Lab teaching and learning activities, the first week is dedicated to an open-ended problem with several solutions. This "open-ended problem" strategy is recognised as one of the elements that promotes problem solving skills in the PB Lab learning activities. Several discussion sessions take place among the students and facilitators throughout the four weeks PB Lab course. Students read and define the problem statement by engaging in discussions with their group members and their facilitators. According to Palincsar (1998), this process was a way of ensuring that problem solving took place during the learning process. With reference to the learning perspectives, students will understand the problems more once they have interacted with the people surrounding them (Palinscar, 1998). When students carry out discussions with their group members regarding the problems, strategies to solve the problems and analyse the results are obtained and their minds start to critically think and create meaning based on the information acquired from the interactions. This process leads the students to becoming good problem-identifiers and problem-solvers. Aside from that, the Students' Pack, which consists of general information of the project such as the issues, the PB Lab process time frame, and the list of possible hardware and software tools that could assist the students in planning the solutions, can also help the students independently construct their own ideas and plans, which prevents them from directly follow the lecturer's thoughts (DeVries, 1997).

Table 3.3: PB Lab activities

Weeks	In-Lab session (3 hours)	Out-Lab session (2 hours)
WEEK 1	1. Understanding the project* with guide of facilitator. 2. Brainstorming; giving ideas to solve problems related to the project. 3. Identifying available resources and tools. 4. Identifying what is known and what is needed to be known in solving the problems related to the project. 5. Facilitator marks individual in-lab activities.	1. Get more resources to help understand the problems related to the project. 2. Divide work among group members. 3. Report findings to group. 4. Agree on a solution.
WEEK 2	1. Present solutions to facilitator. 2. Facilitator comments on solutions, making sure the group is on the right track. 3. Group begins to design the experiment. 4. Group confirms the experiment layout. 5. Facilitator monitors and marks individual in-lab activities and log books.	1. Group conducts some simulation work to reconfirm design. 2. Group verifies the availability of equipment and tools to conduct experiments. 3. Group prepares schematics or connection diagrams for experiment.

WEEK 3	1. Group begins to conduct experiment. 2. Facilitator monitors and marks individual-in lab activities and group log books. 3. Group obtains results from experimental work.	1. Group prepares slides for presentation of completed work. 2. Group starts preparing report.
WEEK 4	1. Group presentation and demo. 2. Report writing. (Facilitator monitors and marks individual-in-lab activities and group log books. Facilitators also evaluate all group presentations).	1. Continuation of report writing and submission exactly a week later to the Lab technician to be recorded and given to facilitators.

The PB Lab facilitators are responsible in guiding and facilitating the students' progress when solving the problem or project. Table 3.3 also displays the facilitators' responsibility each week during the PB Lab sessions and it indicates the importance of facilitation in ensuring the smooth progress of the PB Lab course. (Azli *et al., 2012)* stated the roles of facilitators in this PB Lab course as:

1. To facilitate each group in a laboratory session in solving a problem or conducting a project.
2. To evaluate the students' laboratory performance based on the outlined evaluation criteria.
3. To ensure that the evaluation process is completed according to schedule for each assigned problem or project.

Besides that, in order to ensure that the required programme and course outcomes are achieved, it is important that the PB Lab facilitator assess the students appropriately based on their achievements.

3.2.1.3 PB Lab Assessments

Assessments play an important role in the teaching and learning process. Students regard them as important, as it defines how they spend their time and their interpretation as a student, as well as a graduate. Essentially, assessments consist of taking a sample of what students do, making inferences from it, and estimating the worth of their actions. The sample may include solving problems, writing essays, reporting solutions, and many more, while the sampling may be undertaken by the students themselves, their peers, and their tutor, or whoever they are working with (Brown *et al*., 1997). Watskin and Hattie (1985) stated that the type of assessment will influence their learning style. This implied that an assessment is one of the most important elements that require careful and meticulour design so as to enhance students' skills and knowledge.

For the PB Lab course, the decision of the assessment methods were made by the PB Lab Task Force members (Azli *et al*., 2012), after a thorough discussion among the PB Lab facilitators. This is to ensure that the chosen evaluation methods are in line with the objectives of the faculty. To evaluate and assess the students, several assessment methods have been chosen to be implemented in the PB Lab course. Table 3.4 shows the list of the PB Lab assessment methods:

Table 3.4: PB Lab Assessments

No.	Assessment Method	Percentage (%)
1.	Individual in-lab activities (4x)	20
2.	Peer Review	10
3.	Logbook	30
4.	Presentation	20
5.	Report	20
	Total	100

Based on Table 3.4, two types of assessments are used in the PB Lab course: the individual assessment and group work assessment. Only one assessment method falls under the individual assessment, which is the individual in-lab activities, while other assessments fall under the group work category. They include writing a logbook, group presentation, and a group report. In addition, all of the assessment methods in Table 3.4 allow the PB Lab facilitators to evaluate the students' performances, excluding peer and self-evaluation. Both evaluations allow the students themselves to evaluate their group members individually in terms of their cooperation, attitude, and performances. Based on the PB Lab assessment methods, it is shown that the PB Lab course does not only focus on the achievement of the group work, but also takes into account the development of the knowledge and skills of each student as an individual. Besides that, it can also be seen that the individual in-lab activities stated (4x) and this means that the individual in-lab activities assessment has to be completed by the facilitators in Weeks 4, beginning from the first week the students enter the laboratory. Similarly, the log book assessment is evaluated every week following the first week, while the other assessment methods are evaluated at the end of every four weeks.

Referring to Table 3.4, it can be stated that there are two types of PB Lab assessments used: formative and summative assessments. Formative assessments are conducted by the lecturer on the students while the teaching and learning process is ongoing, while summative assessments are conducted on students at the end of each instruction or class to assess their overall performance (Moreno, 2010). According to MacMillan (2007), formative assessments are useful if they are informative and aligned with the curriculum taught as timely and frequently. The two types of formative assessments used in the PB Lab course are the individual in-lab activities and the group logbook, whereas the summative assessments consisted of the peer and self-evaluation, presentation, as well as reports. To help the PB Lab facilitators assess the students' knowledge and skills more effectively, rubrics were developed and implemented according to the different assessment methods

3.2.1.4 PB Lab Rubrics

According to Moreno (2010), rubrics are the scoring scales that describe the criteria applied for grading subjective assessments. It provides a guideline for lecturers to assess their students fairly and justly. Studies have found that when the rubrics were given to the students ahead of time, they guide the students' focus and increase their performances (Arter and McTighe, 2010). With that said, the PB Lab Task Force members selected the rubrics to be one of the tools to assess students' performances and their skills (Azli, 2005). Based on the above discussion, several individual and group assessments were implemented in the PB Lab course and they used rubrics as the scoring tools to assess the students' achievement and progress in solving problems in the lab. Figure 3.1 shows an example of the individual in-lab activities rubrics form used by the PB Lab facilitators. There are three main characteristics in the design, including the criteria, levels of the students' achievements, and the descriptors under each level. Generally, the "criteria" in the rubrics were selected by the PB Lab coordinator who is responsible for designing and distributing it to other PB Lab facilitators. Specifically, the criterion listed in the PB Lab rubric also depended on the required outcomes of the PB Lab course itself.

No.	Criteria	Excellent 4	Good 3	Fair 2	Poor 1	Individual Score			
						W1	W2	W3	Total
1.	Punctuality	Arrive on time, fully utilizing lab hours.	Arrive on time, but not fully utilizing lab hours.	Up to 5 minutes late.	More than 10 minutes late.				
2.	Discipline *Dress codes, laboratory regulation & safety*	Conform to lab's dress code and all lab regulation & safety.	Conform to lab's dress code and nearly all lab regulation & safety.	Conform to lab's dress code and nearly all lab regulation but with minor flaws in safety.	Does not fully conform to lab's dress code or major flaws in lab's safety.				
3.	**Proficiency in Using Lab Equipment and/or Software** *The student demonstrates skill and understanding in using lab hardware and software*	Able to sets up equipment and collects data in an **efficient** manner. Fully utilise the software tools to analyze and display the data collected	Able to sets up equipment and collects data in an **efficient** manner **but not** fully utilise the software tools to analyze and display the data collected	Able to sets up equipment and collects data in **less efficient** manner **and not** fully utilise the software tools to analyze and display the data collected	Not able to set up equipment and utilize the software tools.	____ x 2 =____	____ x 2 =____	____ x 2 =____	____ x 2 =____
					TOTAL INDIVIDUAL SCORE (MAX 48)				

Figure 3.1: Example of Individual In-Lab Activities Rubrics Form

Apart from that, in the PB Lab rubrics, four levels of the students' performances are set to be in the range of 1 to 4, with 1 rated as poor, followed by fair, good, and excellent for each of the component under each criterion. For other examples of the PB Lab rubrics, refer to Appendix F for details.

As mentioned in Chapter 1, the main purpose of this study is to develop a Problem solving Process Rubrics (PPR) to assess students' problem solving skills in the PB Lab course. Multiple data collection methods such as interviews, observation, documents review, and rubrics were collected and analysed to further strengthen and validate the final findings. As stated by Yin (1994), the multiple data sources in a case study design are like strategies to enhance the credibility of the data. Each data source was analysed individually and then triangulated with data from other sources, resulting in the final findings that can promote great understanding of the case. Hence, the details of the data sources and analysis used in this study are presented below.

3.3 Research Framework

The ultimate goal of this research is to design a Problem solving Process Rubric (PPR) that can assess students' problem solving skills in the PB Lab course. There are three main phases of this study, which are:

a. Phase I: Identification of problem solving process that occured in the PB Lab course
b. Phase II: Development of the Problem solving Process Rubrics (PPR)
c. Phase III: Validation of the Problem solving Process Rubrics (PPR)

To understand more, the research framework of this research is illustrated in Figure 3.2. As seen, there are column of literature at the left side and the data collection column at the right side of the framework. Both columns are the data that has been used to support and achieve the research objectives.

In Phase I, the objective was to identify the problem solving process that occurred in the PB Lab activities. There are two theories which have been referred by researchers in this phase which are Constructivism Theory and Woods *et al.* (1997) Problem solving Process model. The Constructivism Theory that discusses about how individuals construct meaning in mind, based on interaction with peers and this theory triangulate with the Woods' problem solving process. Both theories and models helped the researcher to focus only on the PB Lab activities which relate to the problem solving process. Besides that, in the context of this study, the problem solving process which leads the students to solve the problem in PB Lab course are determined based on two data collections such as observations and interview methods. As known, the observation method is the suitable method to closely watch the people and activities happening, whereas the interview helped the researchers to get more detailed explanations regarding the activities that occurred in PB Lab from the PB Lab facilitators. By observing the PB Lab students' activities and interviewing the PB Lab facilitators related to problem solving, the lists of problem solving process determined by researchers during the PB Lab course have been compared and triangulated with the Woods Problem solving Process. This triangulation process helped the researchers to make sure that the findings obtained were relevant to the Theory of Constructivism and Problem solving Process proposed by Woods *et al.* (1997) as well as achieve the objective of Phase I.

Next, in Phase II and III, it can be seen that the concept referred was the same. The Mertler's Rubrics Development Process has been used by researchers in developing a valid rubric in Phase II and Phase III. The main objective of Phase II of this study was to develop a Problem solving Process Rubrics (PPR) in assessing students' problem solving skills in PB Lab course while the aims of Phase III was to examine the content and construct validation of the PPR. In designing the rubrics, the step-by step process of rubrics' development proposed by Mertler's (2001) guided the researchers to focus on the content of the rubrics' design itself including the rubrics' criteria, descriptors and students' level of performances. A general step-by-step process of the rubrics development was reported by Mertler (2001), which was compiled from various researchers (Airasian, 2000 and 2001; Mertler, 2001; Montgomery, 2001; Nitko, 2001). The steps of the rubrics development are as follow:

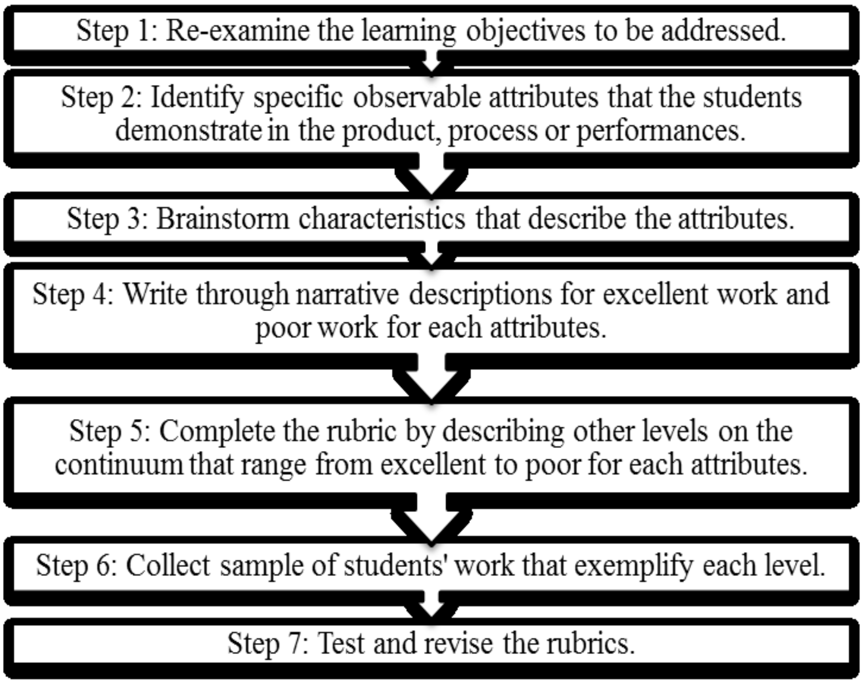

Figure 3.2: Mertler's Rubrics Development Model

There are seven steps of Mertler's (2001) rubric development. In this research, all the steps have been followed and refered by researcher in order to make sure the PPR design are valid and systematically designed. However, throughout the process in developing PPR, Mertler's (2001) step six which is "collect sample of student's work that exemplify levels" have been implemented by using interview session. No sample of student's work been gathered but the sample of students' attributes have been differentiate by researcher and it can be used for exemplify.

Due to that, several data collections have been used by researchers in these phases to gather the findings that can help in developing good PPR designs. The data collection such as interviews and documents was triangulated to make sure that the criteria, and the problem solving process included in the PPR was relevant and assesses what it has to assess. Then, the final PPR design was been validated by experts. It is to make sure that the PPR design was valid in terms of its content and construct. So, based on the results obtained from each phases as explained above, a valid Problem solving Process Rubrics (PPR) that measures and assesses students' problem solving skills in the PB Lab course have been designed. Most importantly, the design of the rubrics is based on the specific problem solving process required in engineering project-based laboratory context. Figure 3.2 shows the framework of this research.

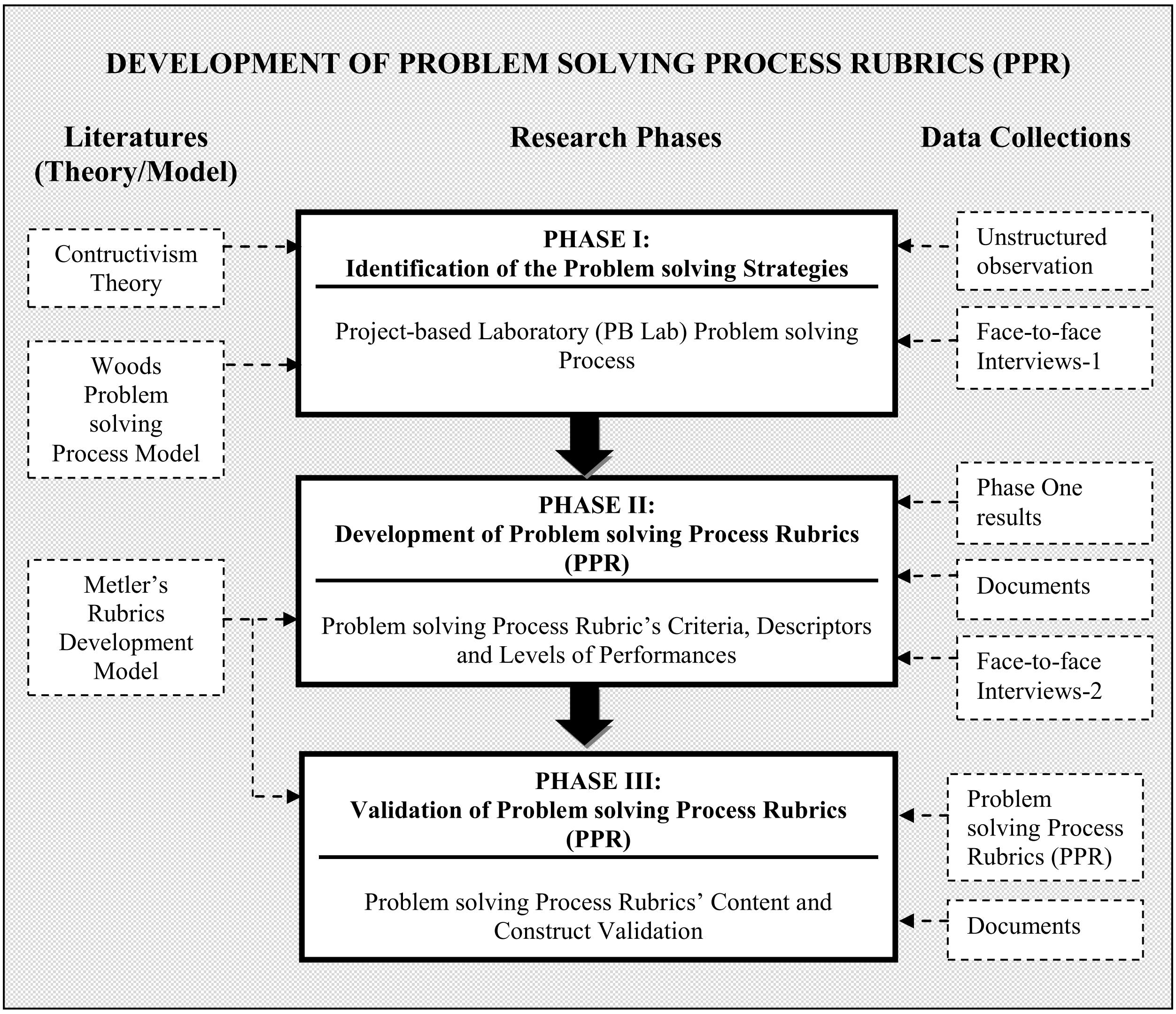

Figure 3.2: Research Framework

Table 3.5 shows the several data collection methods used in this study such as in as interviews, observation and review of public documents. These data were collected to further understand and obtain the problem solving process that occur in the real PB Lab setting, which are to be included in designing valid rubrics criteria, descriptors, and levels. In addition, Table 3.6 also summarises the alignment between research objectives, research questions, data collection methods, and the data analysis techniques applied in this study. All these data lead to an effective and valid design of the Problem solving Process Rubric (PPR) to improve the problem solving assessment for PB Lab.

Table 3.5: Types of Data Collection and Labels

Data Collections Methods	**Implementation** Phases	Data Label #
Observation	Phase I	Data set 1
Interview	Phase I Phase II	Data set 2 Data set 3
Documents	Phase II	Data set 4
	Phase III	Data set 8
PPR (Ver. 1) PPR (Ver. 2) PPR (Ver. 3)	Phase III Phase III Phase III	Data set 5 Data set 6 Data set 7

Table 3.6: Summary of the research objectives, research questions, data collection and data analysis

Phases	**Research Objectives**	**Research Questions**	**Data Collection**	**Data Analysis**
I	To identify the problem solving process that occur in the PB Lab course activities to be included in designing the PPR.	i. What are the problem solving process that occur during the PB Lab activities?	i. Observation (Data set 1) ii. Interviews (Data set 2)	Thematic Analysis
II	To construct the rubrics' criteria, descriptors and levels of performances related to problem solving skills to be included in the PPR design.	ii. What are the criteria of the problem solving process appropriate to be include in the PPR design? iii. How many levels of the students' performances that need to be included in the PPR design? iv. What are the descriptors of the students' performances which are appropriate to be included in the PPR?	i. Phase I result ii. Interviews II (Data set 3) iii. Documents (Data set 4)	i. Thematic Analysis ii. Document Analysis

III	To examine the validity of the PPR design, including the content and construct in assessing problem solving process in the PB Lab course.	v. Does the PPR measure the required problem solving outcomes it is intended to measure? vi. Are all of the important aspects of problem solving outcomes evaluated through the PPR?	i. PPR (Version 1,2,3) (Data set 5, 6, 7) ii. Documents (Data set 8)	Thematic Analysis

To understand more about each phase, a detailed explanation, as well as the Mertler's step-by-step process is provided.

3.3.1 Phase I: Identification of Problem solving Process that Occurred in PB Lab Course

As stated by Mertler (2001), the first step in developing rubrics involving the researcher was to select the learning objectives that needed to be addressed and identified. This study focused specifically on the problem solving skills as the main learning objective to be assessed. Problem solving skills was chosen due to the high demand from the engineering accreditation board and industries from among graduates (Paton,2010; Idrus *et al.,* 2010). After the learning outcomes were determined, the specific observation attributes that the students demonstrated in the product, process or performance in relation to the learning outcomes were also identified. In their previous research, Mertler (2001) and Nitko (2001) stated that, in developing the rubrics, the learning objectives to be assessed must align with the learning process observed. Therefore, during this phase, a number of qualitative data were collected by the researcher in order to identify the problem solving process that occurred during PB Lab activities.

Two sets of data were collected during this phase I: Data set 1 (observation field notes) and Data set 2 (interview transcripts). Both data were triangulated and resulted in the problem solving process that occurred during the PB Lab activities. These data helped the researcher begin designing the problem solving rubric criteria and descriptors in Phase II. The learning process related to problem solving provided the researcher with an overview of the problem solving process that happened during the PB Lab session from the first week until the fourth. It is crucial to highlight that the identification of the problem solving process in PB Lab was through a theory-driven strategy, where the observed problem solving process was compared with Woods' problem solving models (Woods *et al.,* 1997). This was to ensure that the problem solving process identified by the researcher was aligned with the other recognised problem solving models. Hence, by using the identified problem solving process, the criteria and descriptors in the Problem solving Process Rubrics (PPR) in Phase II were developed.

A clear view of the Phase I framework is illustrated in Figure 3.4 and the following sections provided details of the data collection and analysis.

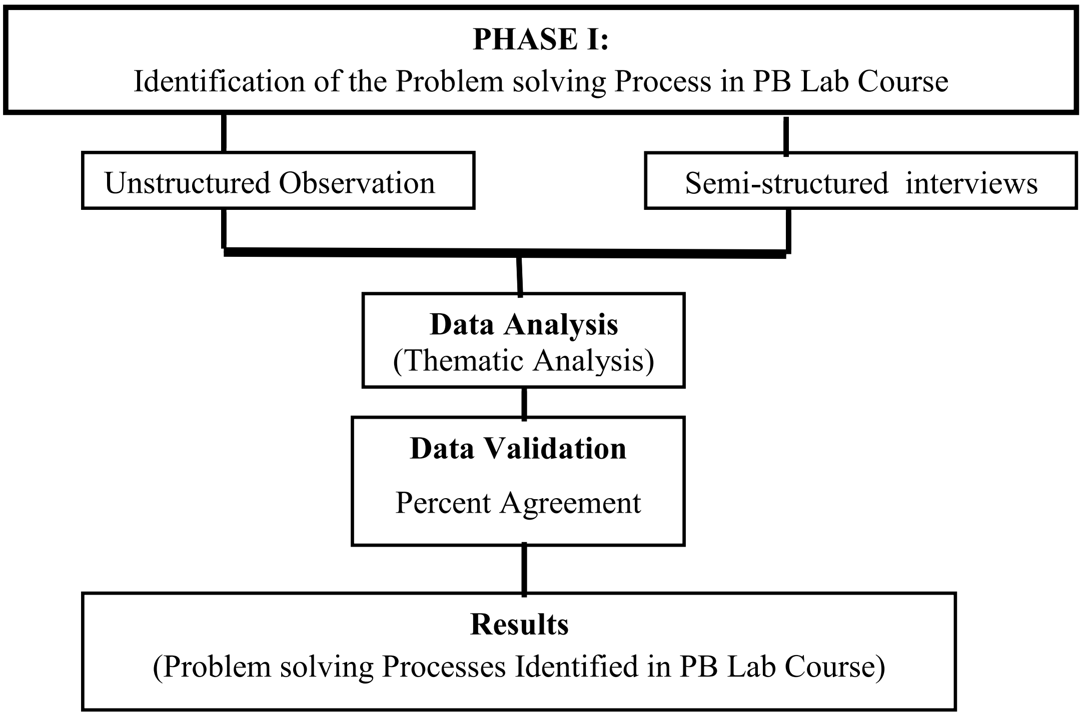

Figure 3.4: Phase I framework

3.3.2 Phase II: Development of the Problem solving Process Rubrics (PPR)

Phase II of this study involved steps 3, 4, and 5, until step 6 of Mertler's (2001) rubrics development model. The rubrics' part including the criteria, descriptors, and levels of the students' performance were developed systematically by the researcher based on the data collected in Phase II. Previous results of Phase I data collection had been taken into account to design the Problem solving Process Rubrics (PPR), as the results obtained in Phase I were based on the problem solving process, which is the main learning outcome assessed in Phase II. Hence, three important data were used in Phase II, which were the Phase I results (themes), interviews II, and some documents. These data sets were triangulated and used by researcher as supportive data when designing the Problem solving Process Rubrics (PPR). In this phase, the Mertler's rubrics development (2001) starting from step 3; brainstorm the students' character that describe the attributes until step 5; describing the level of performance were implemented by researcher in designer valid PPR design. However, the step 6; collect samples of students work were obtained from the data of Phase I (observation and interview I). Based on the observation in Phase I shows variety of students' characters during the PB Lab learning session. This variety helped the researcher to differentiate the students' work as well as the rubrics levels.

In detail, the objectives and functions of these data sets with rubrics development are as follow:

Table 3.7: Objectives and Function of Data sets in Phase II

Data Collection (Data Sets)	**Objectives of Data Sets**	**Function for Rubrics' Development**
Phase I results (Data set 1 and Data set 2)	• to identify the problem solving strategies that occurred during PB Lab activities. • to obtain samples of students' attributes related to problem solving skills during PB Lab activities.	Rubrics Criteria, Descriptors, and Levels
Interviews II (Data set 3)	• to obtain the PB Lab facilitators' opinions about the previous rubrics criteria, levels, and descriptors.	Rubrics Criteria, Descriptors, and Levels
Documents (Data set 4) • Engineering Accreditation Council (EAC) Manual Report • PB Lab course documents • Existing Problem solving Rubrics	• to get an overview of EAC programme outcomes and PB Lab course outcome requirements related to problem solving skills. • to get an overview of the existing problem solving rubrics assessed and to familiarise with the rubrics' language.	Rubrics Criteria and Rubrics Descriptors

Based on Table 3.7, the importance of each data collection in guiding the researcher in designing the Problem solving Process Rubrics (PPR) to assess students' problem solving skills in the PB Lab course is shown. A summary of the Phase II of this research is described as in Figure 3.4. The following sections provide details of the Phase II process.

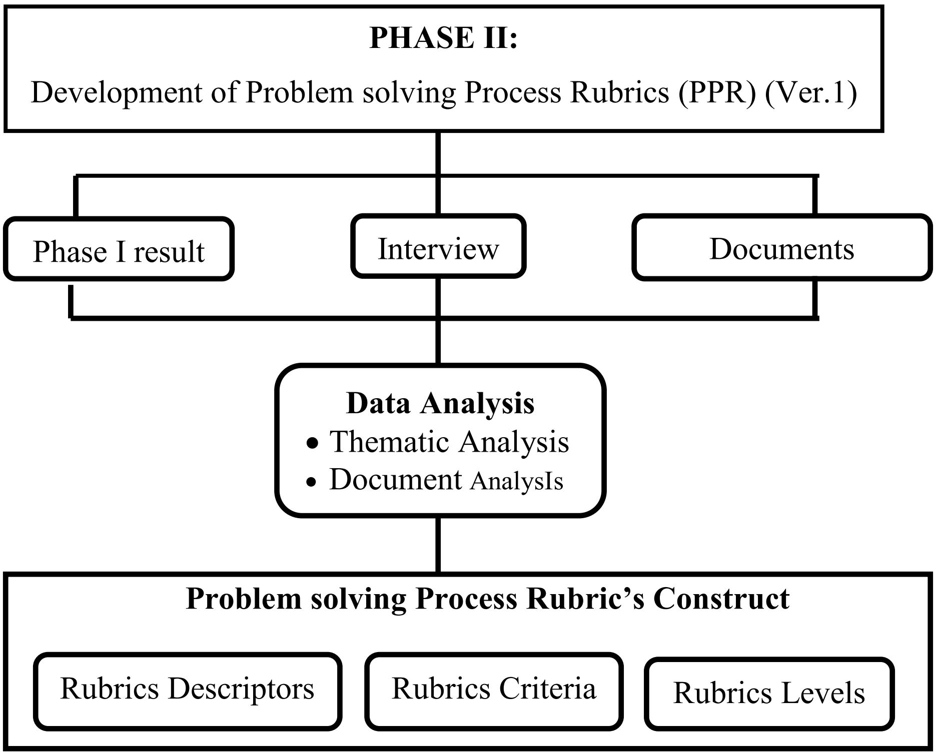

Figure 3.5: Phase II Framework

3.3.3 Phase III: Validation of Problem solving Process Rubric (PPR)

Phase III of this study involved the seventh step of Mertler's (2001) rubrics development model. This also included the final step of the rubrics development, which is the rubric's testing. In designing the rubric's instrument, the validity of the rubric's design was highlighted as an important aspect (Jonsson and Svingby, 2007) before the rubrics were implemented. Validity of the rubrics referred to the content of the rubrics itself, whether it could measure what it was intended to measure (Jonsson and Svingby, 2007; Alfrey, 2009; Moskal and Leydens, 2014). In this research, after the first version of the Problem solving Process Rubrics (PPR) (Data set 5) was constructed, the rubrics underwent the validation process to validate the rubrics. Three experts reviewed and validated the rubric's constructs and content. Next, in order to verify the PPR's content based on industryperspectives, three experience engineers have been gathered and be given one checklist including the PPR criteria. Generally, the framework of Phase III is shown in Figure 3.5.

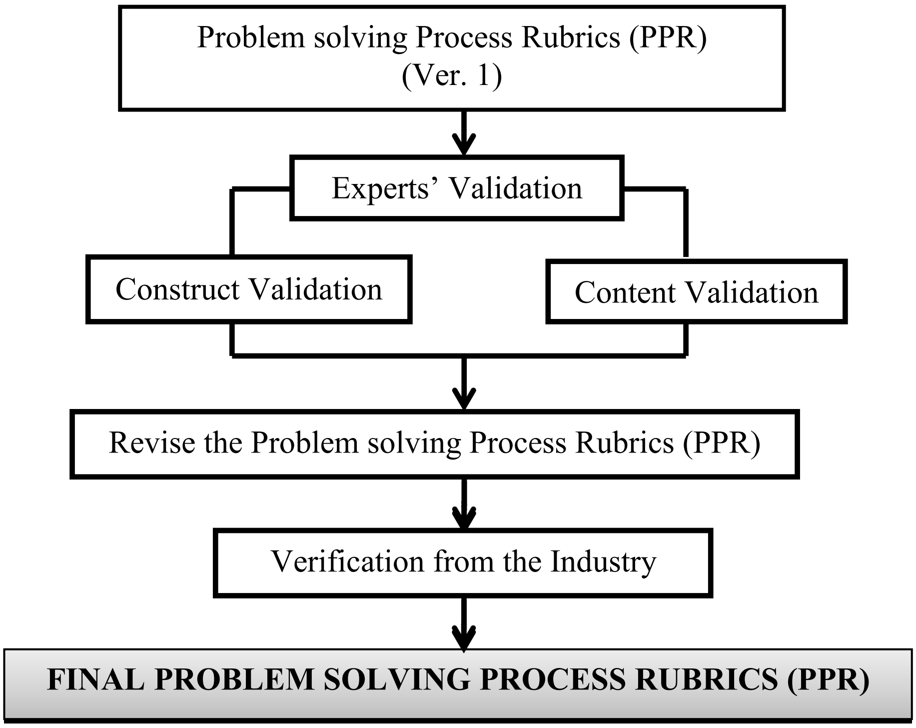

Figure 3.6: Phase III Framework

3.4 Research Operational Framework

As a whole, the operational framework for this study is as shown in Figure 3.7. The operational framework not only proved beneficial in guiding the researcher, but also to describe to the reader the process of data collection and data analysis to achieve the main objectives in a systematic manner.

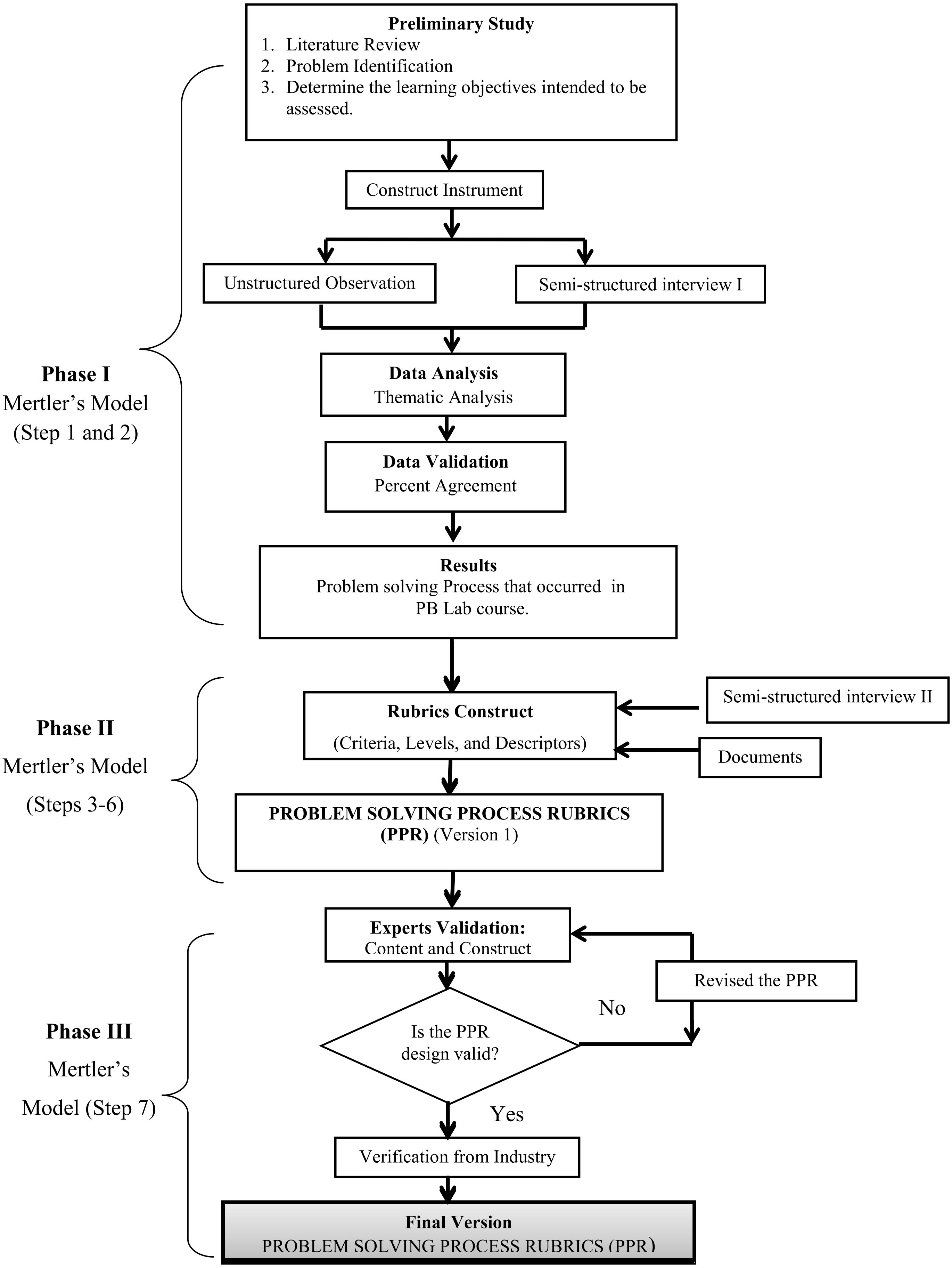

Figure 3.7: Research Operational Framework

3.5 Research Participants and Setting

3.5.1 Participants

In this study, the main objective to be achieved is to develop the Problem solving Process Rubrics (PPR) for the project-based laboratory particularly in PB Lab course in assessing students' problem solving skills. According to Onwuegbuzie and Collins (2007), if the research findings do not focus on the generalisation of the population and obtain insight of the phenomenon, individuals, or events, it is related to purposive sampling (Onwuegbuzie and Collins, 2007; Battaglia, 2011). Purposeful sampling is a technique widely used in qualitative research which involved selection of individual or groups that are knowledgable or have experienced with the phenomenon (Patton, 2002; Cresswell and Plano Clark, 2011).

Therefore, the main participants involved in this research were the fourth year electrical engineering students and PB Lab facilitators. They were selected by the researcher as the participants due to their experience that have gone through the PB Lab activities from week one until week four as students or experiences in conducting and assessing students during PB Lab sessions as facilitators. Therefore, they have the purpose of answering the research questions and objectives of this study. Specifically, nineteen students (include 3-4 students per group) from Bachelor of Engineering-Electrical (SKEE) program were selected to be observed during Phase I of this study. Instead of that, there are four PB Lab facilitators were selected as participants in observation process and seven facilitators (P1-P7) were chosen to be interviewed in Phase I. While in Phase II, six facilitators (P8-P13) were selected for interview II. All of them are from Faculty of Electrical Engineering (FKE), Universiti Teknologi Malaysia (UTM). The details of the participants involved were reported in Table 3.9 and Table 3.11.

However, in order to verify the PPR development in Phase III, three experiences engineers have been selected. The details of the engineers involved were reported in Table 3.17.

3.5.2 Setting

This research was conducted during the PB Lab course at the Faculty of Electrical Engineering, Universiti Teknologi Malaysia. The PB Lab is a 4th Year Undergraduate Laboratory course that has been conducted since 2007 with two credit hours. It successfully replaced the conventional instruction-based laboratory course in the Bachelor of Engineering (Electrical) programme curriculum by having a student-centred approach rather than a teacher-centred approach. In this PB Lab course, each group of students are required to solve a given problem within four weeks. Thus, the students are expected to spend 12 weeks in a semester to complete all the problems or projects. The experiments conducted can be software-based, hardware-based or both, depending on the laboratory requirements. Students basically spend 3 hours per week in their respective laboratories with facilitation, which is known as the in-lab sessions (with a total of 36 hours). In addition, they also need to meet at least 2 hours per week outside the laboratory hours to further discuss the problem or project with their group members. This is known as the out-lab sessions (with a total of 24 hours). The three different programmes involved in this PB Lab course in Semester 2014/2015 make up 10 laboratories. Table 3.8 shows a detailed description of the programmes involved in the PB Lab course and their course codes.

Table 3.8: PB Lab Laboratory for Bachelor of Electrical Engineering

Program/ Program Code	PB Lab Course Code	PB Lab Laboratory Involved
Bachelor of Engineering (Electrical) / SKEE	SKEE 4722	Power Electronic Laboratory (PEL)
		Advance Power Laboratory (APL)
		High Voltage Laboratory (HVL)
Bachelor of Engineering (Electrical-Electronic)/SKEL	SKEL 4722	VLSI System Design Laboratory (VLSI & ECAD)
		Digital Electronic Laboratory (DSP)
		Advance Electronic Laboratory (Microelectronic)
		Microprocessor Laboratory
Bachelor of Engineering (Electrical-	SKET 4722	Basic Microwave Laboratory
		Radar Communication Laboratory

Telecommunication)/ SKET		Optical Communication Laboratory

3.6 Data Collection Methods

There are three main data collection methods in this study, which are unstructured observation, semi-structured interviews and documents. All these data are necessary to achieve the main objective of this study. Besides that, by collecting different kinds of data using multiple data collection methods, the validity and credibility of the findings cannot be denied (Creswell, 2003). As a pragmatist, the findings from multiple data collection help the researcher mix and triangulate the data without committing to only one method (Creswell and Miller, 2010).

3.6.1 Unstructured Observation

At the early stages of Phase I data collection, the observation method was conducted. This qualitative method creates an understanding of how the PB Lab course was run, as well as the student activities in the PB Lab that involve the problem solving process. Furthermore, by using observation, the researcher can personally observe the participants' attributes and listen to their conversation with the purpose of gathering data (Dalen, 1979), while also watching the participants and the ongoing activities (Mulhall, 2003) specifically in a real PB Lab setting with an open-ended view, rather than being limited to only a certain area for the observation. Moreover, the role of the researcher in this research as a non-participating observer is like an "outsider" who visits the lab and records the phenomena without participating in the activities conducted in the PB Lab setting. With this, the researcher is then able to focus solely on the natural phenomena in the given setting.

Hence, to make sure that the observation data are recorded effectively, "field notes" were used for this research. According to Cresswell (2012), field notes are texts or words recorded by the observer during the observation process. It is a method that encourages the observer to record the observations in a narrative and descriptive way. For the purpose of this research, a field notes table was developed. It was divided into two columns: (i) a descriptive column, which recorded the people and activities happening in a descriptive way; and (ii) a reflective column, which recorded the researcher's thoughts, understanding, and questions throughout the observation process. The design of the field notes table in this study was adapted from the one proposed by Creswell (2012). The table also included time, place, length of observation, participants, subjects, and the objectives studied (refer to Appendix A).

To ensure that the observation data was valid, the research samples selected must be samples of a population who are relevant to the research questions. In this study, purposive sampling was selected. Table 3.9 shows the details of the purposive samples and the setting used for observation.

Table 3.9: Research Participants and Setting

No.	Subjects	Research Participants and Setting
1.	Programme	Bachelor of Engineering (Electrical) / SKEE
2.	PB Lab course code	SKEE4722
3.	Participants	19 final year Electrical Engineering students (three to four students per group)
		4 PB Lab Facilitators (one facilitator per group)
4.	Setting	Power Electronic Laboratory (PEL)
		Advanced Power Laboratory (APL)

The researcher thoroughly observed and recorded the PB Lab activities for 3 hours in each lab. The PB Lab course under the Bachelor of Engineering (Electrical) (SKEE) programme was selected for observation by the researcher. SKEE consists of core and specialized electrical engineering course (Faculty of Electrical Engineering, 2017) and have the larger students enrolled every year compared to other course. The observation began in the first week and proceeded until the fourth week of PB Lab course. The observation process provided an overview for the researcher to understand the process of the PB Lab activities, as well as the participants' attributes towards the PB Lab activities that are related to problem solving. According to Taylor-powell (1996), observation strategy is useful when the researcher is attempting to understand and determine the behavioural progress, process, and unfolding event. The statement supports the use of observation methods in Phase I, where the process of problem solving, as well as students' attributes in PB Lab course was the main objective to be analysed. Though there are disadvantages to using observation that will affect the data collection, such as "feeling awkwardness of being an outsider" at the early stages of the observation process (Hammersley and Atkinson, 1995). Such a limitation was tackled by the researcher by conducting "site visit" before the first observation started in order to familiarise with the research setting. This also helped build a rapport with lab technician and PB Lab facilitators. Besides that, a general briefing regarding PB Lab activities was done by the PB Lab technician during the site visit, which managed to create a clearer overview of the activities that will be observed. The observation tackling solution implemented by the researcher was supported by Creswell (2012).

3.6.2 Semi-Structured Interview

Most researchers are aware that an interview is the most widely used approach when collecting qualitative data. Potter (1996) stated that interviews collect data from people by asking them questions and obtaining verbal responses. Hence, this research used the face-to-face interview as one of the main data collection methods, specifically semi-structured interviews (Hancock, 1998). Generally, they involve a series of open-ended questions constructed based on the research areas and provide opportunities for both the interviewer and participants (interviewees) to discuss a topic in detail. If the interviewee has difficulty in answering a specific question, the interviewer can encourage the interviewee to consider the question further (Hancock, 1998).

In this research, the interview sessions were conducted twice, which are Phases I and II. The objectives of each interview session are different for each phase. Table 3.10 shows the main objectives of the interview session based on the phases.

Table 3.10: The Interviews Objectives

Phases	Data Collection / Data set	Objectives of the Data Collection
Phase I	Interview / Data set 2	• To identify how the PB Lab facilitator conduct the PB Lab course from the first week until the fourth.
Phase II	Interview / Data set 3	• To identify the PB Lab facilitator's comments and opinions regarding the previous PB Lab rubric design (rubric's criteria, descriptors, and levels).

Table 3.10 described the use of interview as a data collection method in developing the Problem solving Process Rubric (PPR). The data gathered from the interview sessions are crucial to supporting and triangulating with other data to increase the validity and credibility of the findings. They also support the design of the rubrics and provide additional information for the researcher in terms of its development and requirement for future improvements. Therefore, to obtain valid data from the interview sessions, the following interview steps defined by Hancock and Algozzine (2006) were used as a guideline.

1. Step One: Identify the participants to be interviewed

As mentioned above, the interview sessions were done twice; first, during Phase I, followed by another in Phase II. All the facilitators who participated in the interview sessions were experienced lecturers (i.e. those with more than five years of teaching experience) and PB Lab facilitators from different Electrical Engineering program. Electrical Engineering facilitators with varying fields of specialisation were selected due to the difference in the labs, such as software-based lab, hardware-based lab, and both software- and hardware-based lab. The triangulation of the interview data gathered from the PB Lab facilitators of varying Electrical

Engineering fields helped the researcher generalise the results and design the Problem solving Process Rubrics (PPR) across different courses. Aside from that, the participants who selected for this interview process were also relevant to the research questions, therefore fulfilling the purposeful sampling strategy (Battaglia, 2011; Onwuegbuzie and Collins, 2007). Table 3.11 shows the details of the participating PB Lab facilitators according to the phases. Specifically, the selected facilitators for these interview session were from SKEE (Bachelor of Electrical-Power) course, SKEL (Bachelor of Electrical- Electronic) course and SKET (Bachelor of Electrical- Telecommunication) course.

Table 3.11: Interviews Participants according to the Research Phases

Phase	Facilitator's Code	PB Lab Conducted	Types of PB Lab	Course	Teaching experience (years)
Phase I	P1	Power Electronic Lab	Software- & hardware-based	SKEE	12
	P2	Advance Power Lab	Software- & hardware-based	SKEE	13
	P3	High Voltage Lab	Hardware-based	SKEE	13
	P4	High Voltage Lab	Hardware-based	SKEE	6
	P5	Electronic Lab	Hardware-based	SKEL	9
	P6	Digital Signal Processing Lab	Software-based	SKEL	29
	P7	Digital Signal Processing Lab	Software-based	SKEL	6
Phase II	F8	High Voltage Lab	Hardware-based	SKEE	6
	F9	High Voltage Lab	Hardware-based	SKEE	13
	F10	Electronic Lab	Hardware-based	SKEL	9
	F11	Radar Communication Lab	Software-based	SKET	16

Phase	Facilitator's Code	PB Lab Conducted	Types of PB Lab	Course	Teaching experience (years)
Phase II	F12	Digital Signal Processing Lab	Software-based	SKEL	6
	F13	Digital Signal Processing Lab	Software-based	SKEL	29

2. Step Two: Develop interview guide (protocol)

To guide the researcher during the interview session, an interview protocol was developed and implemented. The protocol was based on Asmussen and Creswell's (1995) interview protocol guide, which contained (a) introduction header, (b) main and sub-questions of interview, and finally (c) the closing comment. In the introduction header, general information about the interview objectives, their experiences, date, time, and location of the interview were stated. Besides that, the main and sub-questions of the interview were included as the second part in the interview protocol. Most of the questions are open-ended questions that were related to the research questions and research objectives. Lastly, the final part of the interview guide was the closing comment that reminded the researcher to thank the participants and convince them of the confidentiality of their responses. Refer to Appendix D for the template of interview protocol.

3. Step Three: Identify the location to conduct the interview

The interview process was held at the Faculty of Electrical Engineering, UTM and took about one hour to interview each facilitator so that all the important data were gathered. Besides that, the location of the interview was selected by the PB Lab facilitators to ensure that they were comfortable. Therefore, the interviews were conducted in their respective rooms.

4. Step Four: Recording the Interview

According to Merriam (2014) there are three ways to record an interview. However, the most used is the recording of the interview in tape. In this study, a digital recorder was used by the researcher. After recording, the audio was manually transcribed into transcripts by the researcher. Prior to the start of the interview, the participants' permission to record the interview was acquired. The reason why the researcher selected the tape recorder to record the interview session was due to its effectiveness in ensuring all the verbal data during the interview was preserved for analysis. Although the verbatim transcription of the recorded interviews was time-consuming, it gave the researcher the opportunity to analyse the data manually and familiarise with the data obtained.

5. Step Five: Following Ethical Requirement

According to Creswell (2012), several ethical issues are being discussed among many researchers, including confidentiality of the participants' demographic backgrounds, respect of the participants' cultures, and consent forms. In the case of this research, reference labels were assigned to each of the PB Lab facilitators to hide their identity and protect the confidentiality of the PB Lab facilitators' data. Besides that, the PB Lab facilitators' willingness to participate in this study were also obtained before the interview was conducted. The researcher emailed all the participants to inform them of the objectives of the interview, the procedures, the confidentiality of the participants' data, and identification of the participants' willingness to participate in this study. In addition, the indigenous cultures of the facilitators were respected and no provocation of the facilitators with sensitive or personal issues were made. These ethical requirements were suggested by Lincoln (2009) and Creswell (2012).

3.6.3 Documents

Documents are one of the important sources in this research. Documents provide a rich source of information that can be used to support the data collected through interviews and observation (Merriam, 1998; Eisner, 1991). Moreover, by using the documents as a data collection method helped the researcher understand the respondents' views or the phenomena that happened in the research setting better (Creswell, 2012). Besides that, because the documents were already in the form of text, transcriptions were not needed (Creswell, 2012). Generally, there are two types of documents which can be collected, such as public documents and private documents. Hence, in this research, public documents were chosen, gathered and analysed during Phase II and Phase III only. In Phase II, the documents number 1 until 5, as listed in Table 3.12, were collected and reviewed to guide the researcher in the students' outcome of acquiring problem solving skills as required by the Engineering Accreditation Council (EAC) and the PB Lab course. The existing problem solving rubrics in the documents helped the researcher gain familiarity with the rubric's languages, format, and the elements of problem solving skills assessed by other researchers in previous studies and different contexts (Arter and Chappuis, 2007).

Table 3.12: Types of Documents

No.	Types of documents	Objectives
1.	EAC Engineering Programme Accreditation Manual 2012	Provide latest EAC programme outcome requirements.
2.	PB Lab Course outcomes	Provide detailed description of required PB Lab outcomes.
4.	PB Lab Rubrics (semester 2013/2014)	Provide an example of rubric's criteria, levels, and descriptors.
5.	Existing Problem solving Rubrics (15 sets)	Provide samples of problem solving rubrics criteria, level of performances, and description of criteria.
6.	Problem solving Criteria (PPR) Checklists Form	Provide verification of the PPR's criteria in the perspectives of industry.

Instead of that, the rationale for collecting and comparing the existing problem solving rubrics from other researchers and institutions was to give an overview and ideas for the researcher regarding the process of problem solving, which is now commonly assessed in the world of academics. Hence, based on the collected documents show in Table 3.12, the researcher examined and determined the required problem solving skills in EAC documents and also in the PB Lab course outcomes using the document analysis technique. In Phase III, only the document number six were collected; PPR criteria's checklist. This document were also analysed using the document analysis technique. In this research, the documents that selected were key documents that helped the researcher to understand in depth what the required problem solving skills were and how they could be evaluated.. This was crucial to ensure that the problem solving rubrics designed by the researcher not only aligned with the required accreditation outcomes and course outcomes, but also assessed the important problem solving skills recognised by other researchers. More importantly, the results obtained from the document were compared and triangulate to each other. Specifically, in order to analyse all the documents using the document analysis, checklists have been used.

3.7 Data Analysis Technique

As shown before, the data analysis conducted in this study was divided into three parts, namely Phase I, Phase II, and Phase III. The thematic analysis technique was used by the researcher to analyse the interview (Data sets 2 and 3) and the observation data (Data set 1) done manually. Besides that, document analysis was also implemented during Phase II and Phase III of the research to review collected documents. In summary, all the data analysis techniques mentioned above were crucial in helping the researcher construct a valid rubric for this study. A detailed discussion about each data analysis used is provided in the following sections.

3.7.1 Thematic Analysis

Thematic analysis is a qualitative method that analyses and reports the theme of the qualitative data (Braun and Clarke, 2006). It identifies the explicit words or phrases and focused on obtaining the theme of the data. In this research, thematic analysis was used to determine the responses, not only for the Phase I of this study, but also for Phases II. The use of thematic analysis in analysing qualitative data have been recognised by many researchers for its flexibility (Braun and Clarke, 2006). However, up until this day, there are no definite steps on how to do it right (Attride-Stirling, 2001; Boyatzis 1998; Braun and Clarke, 2006). For this, the research's thematic analysis step-by-step process proposed by Braun and Clarke (2006) was used as a guideline to analyse several qualitative data, such as interviews and the observation. According to Braun and Clarke (2006), there are six phases to the thematic analysis: (a) familiarising with the data, (b) generating initial codes, (c) searching for themes, (d) reviewing themes, (e) defining and naming themes, and finally, (f) producing the report. The details of each thematic analysis phases are described as follow:

1. Familiarising with the data

The first process after collecting the qualitative data was transcribing. Transcribing the verbal data to written form has always been seen as a "time-consuming" process. However, it is an excellent way for the researcher to familiarise themselves with the data obtained (Edwards,1993; Bird,2005). In this study, the researcher collected and transcribed the data manually. According to Merriam (2014), by analysing data that were obtained manually, it can increase the researcher's understanding of the research findings. Following the transcribing process, the researcher analysed the transcription by implementing repeated active reading strategy to get comprehensive insight of the findings.

2. Generating initial codes

The second thematic analysis phase implemented by the researcher according to the Braun and Clarke (2006) was generating codes. Codes can be defined as a "basic element of the raw data that can be assessed in a meaningful way based on the phenomenon" (Boyatzis, 1998). According to Braun and Clarke (2006), the code-generation process begins when the data have been read by the researcher and, based on the reading, an initial list of ideas about the data was constructed. For this study, sets of transcribed qualitative data were read and analysed by the researcher manually. For Phase I, the data was analysed and coded by the researcher based on a theory-driven strategy. The problem solving process model proposed by Woods *et al.* (1997) was selected to be the reference in analysing the data in Phase I. On the contrary in Phase II thematic analysis, the data obtained was were analysed and coded using a data-driven strategy. Therefore, in analysing and developing codes for Phase I data, a theory-driven strategy proved more helpful. The strategy became a guideline for the researcher to focus on analysing the transcription related only to problem solving. Table 3.13 shows examples of the interview transcription. It was coded by the researcher to identify the activities that were conducted in the PB Lab course on the third week.

Table 3.13: Examples of data extraction and the codes applied

Data extract	**Coded (activities that occurred in PB Lab course)**
They will connect the devices on week three and normally the connection will have a problem. I will ask them one by one and they have to troubleshoot the circuit until got the correct results.	-Connect the device's connection. -Connection has problem. -Troubleshoot the circuit. -Get the results.
Then, on week three, student will started the experiment and the technician will facilitate them in order to make sure the connection that they build up is correct. Normally, I will look at and check their experiment results. At the end of week three meeting, they must reflect back the output that they got, and what can be conclude based on the results. They have to match the results obtained and the theory behind it.	Start experiment. Build up the connection. Get the experiment results. Check the results obtained.

The researcher took many initiatives before the data were coded as reflected in Table 3.13. The data extract from the transcription were manually highlighted using highlighters and coloured pens with the purpose of differentiating the codes and determining the overlapping codes that can be combined.

3. Searching for themes

In Phase III of thematic analysis, the themes were developed by the researcher based on the list of codes identified in Phase II (Braun and Clarke, 2006). In this phase, all the codes identified must be thoroughly analysed and differentiated. Some codes were combined under on common theme, as they correlated with one another or had the same interpretation. However, certain code were not relevant to the research objectives and were therefore discarded by the researcher. So, in developing the themes of the study, the researcher used mind-maps to sort the codes. Figure 3.8 shows examples of the theme-generating mind-maps based on identified codes.

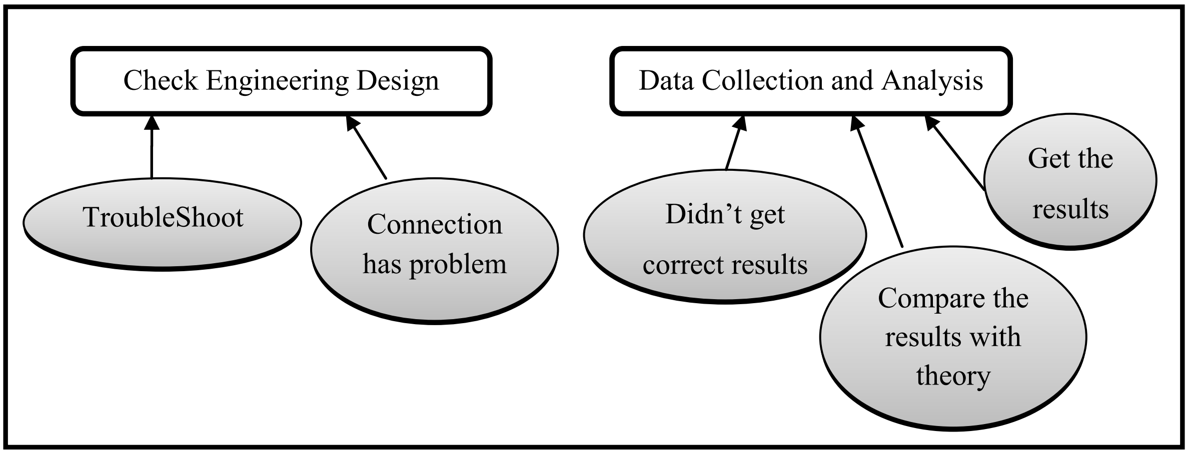

Figure 3.8: Examples of theme-generating mind-maps based on identified codes

4. Reviewing themes

Phase IV began after all the participants' themes were generated by the researcher. Normally, several participants would be involved in the data collection. So, in determining the main themes of the data collected, the sub-themes identified under each participant had to be refined. At this stage, it can be seen that some sub-themes under certain participants' data did not correlate with the others participants' sub-themes, which then required refining (Braun and Clarke, 2006). However, some participants' sub-themes did triangulate with other sub-themes and this led to the development of potential main themes of the study. This phase focused on two processes. They included reviewing and refining the themes. A table to include the entire participants' sub-themes was designed to help the researcher review and compare each of the themes constructed. Should there not be a theme that was not triangulated with other themes, the researcher will review the data extraction and code it once more.

5. Defining and naming themes

After the participants' sub-themes were triangulated and refined, the main themes were defined and constructed by the researcher in this phase. At this point, the main themes had been finalised after thorough analysis to make sure that the themes could correctly answer the research questions.

6. Producing report

The final phase of thematic analysis was preparing a comprehensive written report that is concise, non-repetitive and discussed the findings of the data exactly. This phase is crucial to check the validity of the analysis and make arguments in relation to the research questions (Braun and Clarke, 2006). For this study, a comprehensive and detailed thematic analysis is presented in Chapter 4.

3.7.2 Document Analysis

Document analysis is a method that was used to analyse and review several documents in Phase II of this research. According to Bowen (2009), document analysis is known as the systematic approach to create better understanding, reviewing and evaluating documents with the sole purpose of figuring out the meaning of the data while examining them. With reference to Table 3.12 six types of documents were collected in Phase II and Phase III of this study; (a) EAC Manual Report; (b) PB Lab course documents; (c) PB Lab Rubrics (semester 2013/2014); (d) 15 sets of existing problem solving rubrics and (e) PPR criteria checklist form.

The rationale for using document analysis in this research was to gain better understanding and identify the required programme outcome related to the problem solving skills stated in the EAC Manual report and PB Lab documents. In the process of designing and validating the Problem solving Process Rubrics (PPR) in this research, document analysis was used to compare and examine the existing problem solving rubric designs from other education institutions, as well as industry. In Phase II, several rubric designs were collected from various sources to guide the researcher when designing a state-of-the-art assessment rubric. Besides that, another reason for reviewing these existing rubrics was also to familiarise with the use of the rubric's language and format. Each document collected were thoroughly analysed by the researcher based on the objectives listed in Table 3.12 (number one until five). The content of the documents were reviewed, interpreted, and coded into potential themes using the thematic analysis technique discussed in Section 3.7.1 then, the occurred themes for each documents were triangulate using the checklist. In Phase III, the document six (reported in Table 3.12) were collected and analysed as a final stage in verifying the Problem solving Process Rubric (PPR) criteria in the industry perspectives.

In addition, Denzin (1970) reported that document analysis is commonly used in the combination of other qualitative data collected through different methods, such as interviews or observation. The same combination method was also used in this research and the results of the document analysis were triangulated with the interview results and observation data. The triangulation of data from various sources is recognised to provide high credibility and validity of the data (Eisner 1991; Creswell, 2012).

3.7.2.1 Checklists

According to Kuhs *et al.* (2001), checklist is a simplest form of scoring guide which have been used by researchers in supporting their data collection. In the research done by Baharom *et al.* (2013), the checklist has been used as an assessment form to identify the levels of students' skills. According to Mertler (2001), usually the checklist are used with the performance assessments. In this study, checklist has been used as a supportive tools to align all the data collection in Phase II.

3.8 Quality of the Qualitative Data Findings

Generally, the trustworthiness of qualitative data is often questioned by many people, especially on its validity and reliability (Creswell and Miller, 2010). According to Gibbs (1997) qualitative validity refers to the researcher analysing the findings by employing several types of data, while qualitative reliability indicates that the researcher's findings are consistent with those of other researchers. To ensure the validity of the qualitative data, several strategies were undertaken to conduct this study. They are as follows:

a) Percent Agreement Measurement

Besides validating the research data, the reliability of the findings must also be determined to ensure it is consistent with view of other researchers. That way the different raters or observers have made the same estimation of the same phenomena (Multon, 2012). In Phase I of this research, the findings obtained from the observation and interviews were triangulated and analysed using the Percent Agreement measurement to check whether the findings were also agreed by other experts. Besides the validation process, three experts were brought in to rate the rubrics in the Form of Agreement provided by the researcher. Their responsibilities included reviewing, checking and validating the qualitative findings obtained by the researcher, especially the Phase I qualitative data. The first expert was an experienced PB Lab coordinator specialization in Electrical (Electronics) at the Faculty of Electrical Engineering for nine years. The second expert was an experiences lecturer who is specialization in Electrical (Telecommunication) and has seven years of teaching experience. Lastly, the third expert who is a senior lecturer of Faculty of Electrical Engineering. She has 16 years of teaching experience and has facilitated students in the PB Lab course since 2004. Therefore, it can be deduced that these experts were suitable to reviewing the Phase I data due to their electrical field knowledge and experiences. A complete Form of Agreement (refer Appendix C), which included the final themes of Phase I findings with a Yes-or-No scale, was given to the experts to be rated. Hence, the results of the rating by the experts were analysed using the Percent Agreement measurement as reported in Table 4.4.

Percent Agreement is a simple method used to compute the consensus estimate of reliability between raters (Multon, 2012; Hunt and Dentistry, 1977). It helped the researcher identify the degree of agreement and gave a simple estimated value of reliability. According to Multon (2012), the percent of agreement is 70% and this measurement is based on the calculation of the total agreement from the raters divided by the number of items. There are other reliability measurements used by other researchers such as the Pearson Correlation Coefficient and Kappa statistics, but the Percent Agreement measurement was selected by the researcher specifically for its flexibility to compute and its ability indicate the raters' disparities compared to the Pearson correlation and Kappa measurement, whereby both tests are sensitive to data distribution and required more calculation time (Multon, 2012; Viera and Garrett, 2005). Although the Percent Agreement can be easily computed, it is important to highlight that raters should be trained to rate the form (Multon, 2012). For this purpose, the researcher met with the selected PB Lab facilitators one by one to explain the process of rating the given forms before data collection began.

b) Triangulation from different sources of data collection and participants

Triangulation between several data collection methods provides high validity of the data (Creswell,2008). According to Creswell (2007), triangulation of the data gathered from various sources help the researcher build justification for the theme. Besides that, the triangulation process is also important, as it can increase the accuracy of the findings determined in several other sources (Yin, 2003). In Phase II of this study, the triangulation method have been used to validate the data obtained. It also served as a guide and helped develop the rubric's criteria, levels, and descriptors of the students' performance in the Problem solving Process Rubric (PPR). These three main parts of the rubric's design were developed based on the three sources of data: the Phase I results, analysis of interview II transcriptions, and the document reviews. To get the final criteria and the description of problem solving skills for the rubric design, the triangulation process was applied. All the data were analysed using thematic and document analysis (vis checklists) before been triangulated with each other. This triangulation process was implemented to examine and find the convergence among multiple data collection methods, which resulted in the final categories or themes in the study (Creswell, 2008; Creswell and Miller, 2010). Each of the data collected in Phase II was analysed through the application of triangulation, where the results were then compared and triangulated with each other to get the final themes or results of the problem solving rubric's criteria, level, and descriptors. The final results of this triangulation process were obtained based on the most dominant themes that occurred across the data sets. This themes were then been used to design the first version of the Problem solving Process Rubrics (PPR).

By combining various methods of data collection and triangulation, the weakness and the biases that comes from one method could be avoided. Therefore, it is clearly shown that the final findings obtained for this study from the triangulation process will be accurate as they were obtained and developed based on several methods of data collection, individuals and processes (Cresswell, 2008). A detailed report and discussion on how the triangulation process was implemented and analysed by researcher is presented in Chapter 5.

In conclusion, there is no "best" reliability approach that can be determined (Multon, 2012) because each approach have its own strength and weakness. Therefore, it is important to select the reliability technique not because of it's the "best" approach, but because of its characteristic that suits with the research goal, natural of data and available resources.

3.9 Validity of the Problem solving Process Rubrics (PPR) Design

The importance of validity for the development of assessment cannot be denied. The assessment has a big implication on the students' level of performance (Jonsson and Svingby, 2007). Therefore, the design of the assessment should be credible and reliable (Jonsson and Svingby, 2007) to ensure that the assessment truly displayed the students' knowledge or skills. In this study, the rubric is the assessment tool selected and designed by the researcher. Therefore, the validity aspect of the rubric development was recognised as an important element that should be considered while developing its design (Alfrey, 2009; Jonsson and Svingby, 2007; Moskal and Leydens, 2014). Validation of the rubric design was one of the important and concerning aspects highlighted by many researchers to check whether the rubric truly reflected the variables assessed.

Though there are several aspects of validity investigated and mentioned in the literature reviewed, only two types of the validation process became the focus in validating the Problem solving Process Rubrics (PPR). They were the content and the construct validation. Both these aspects have been commonly examined by other studies (Moskal and Leydens, 2014; Jonsson and Svingby, 2007) . Specifically, in this study, the "expert review" have been collected in order to validate the rubrics especially in terms of its content. According to Jonsson and Svingby (2007), "expert review or opinion" has become one of the frequent method in investigating the rubric's validity. This statement have been supported by several researchers; Mozaffari (2013), Egodawatte (2010) and (Nicholson et al. 2009) who also used and implemented this "expert review" method to validate their rubrics. This shows the importance of the rubrics' development and validation process that need to be reviewed by the experiences experts who understand the purpose of the rubrics' design and the outcomes that need to be achieved by researcher (Jonsson and Svingby, 2007).

So, in this study, the need for the validation process was consistent with the third research objectives (RO3) of this study. The aim was to check whether the

Problem solving Process Rubric (PPR) developed by the researcher correctly measured the problem solving process among the students during the PB Lab sessions.

a) Experts Review

Expert review is one of the evaluation strategies used to validate the research data (Shenton, 2004; Simon, 2011). This strategy proved effective in providing the researcher with a critical review of the important aspects of the study (Simon, 2011). Hence, in this research three experts were choose based on their expertise to review and validate the PPR's design. Therefore, to ensure the validity of the Problem solving Process Rubrics (PPR), three experts have been selected to review, check and validate the Problem solving Process Rubric (PPR) in Phase III. Moreover, the validity of the rubrics have also been thoroughly checked in this study to make sure that the content and construct can be implemented across multiple projects or problems and across programmes. Details of the experts are reported in Table 3.15 and Table 3.16 and the details of the implemented validation process are shown below:

Table 3.14: Types of Validity and Research Questions

No.	Types of Validity	Research Questions (RQ)
1.	Content Validity	v. Does the PPR measure the required problem solving outcomes it is intended to measure?
2.	Construct Validity	vi. Are all of the important aspects of problem solving outcomes evaluated through the PPR?

3.9.1 Content Validity

The first aspect of validation checked by the researcher in this study was the content. The content validation process was done to answer the research question

(RQ) (v) of this study. Content validity refers to "the extent to which a students' feedback or response on the given assessment reflected the students' knowledge of a content area" (Jonsson and Svingby, 2007; Moskal and Leydens, 2014). In short, the validation aspect was to check whether the evaluation criteria in the rubric measured what it intended to measure. Hence, in this research three experts were choose based on their expertise to review and validate the PPR's design. Two experts who were experienced electrical engineering lecturers and another who was an experienced PB Lab facilitator were selected to review the first version of the Problem solving Process Rubrics (PPR) content. Their expertise and experience in conducting and coordinating the PB Lab course was crucial to the validation process, as they were already familiar with the PB Lab structure and the crafting of the projects. The researcher submitted the first version of the Problem solving Process Rubrics (PPR) to the experts to get it validated. This method allowed each expert to thoroughly review the content of the rubrics so that it truly measured the students' problem solving skills, especially on the process they went through to solve the problem. Besides that, the experts were also responsible for checking the alignment between the rubric's criteria and the required programme outcomes.

Table 3.15: Content Validation Experts and Cycles

No.	Experts	Experiences	Types of Validation	Validation Cycles
1.	Expert A	• PB Lab Facilitator (22 years) • Manager in Academic Audit, Accreditation and Recognition Centre for Quality and Risk Management (QRiM), UTM	Content Validation	2 times
2.	Expert B	• PB Lab Facilitator (22 years) • PB Lab Coordinator	Content Validation	2 times

3.9.2 Construct Validity

After the rubric's content were thoroughly checked by the three PB Lab experts, the validity of the rubric's construct were then reviewed. The construct validation processwas done to answer the research questions (RQ) (vi) and (vii). Several studies show that construct validity is an important aspect in instrument development research (Jonsson and Svingby 2007). Construct validity refers to the credibility of the assessment in testing the underlying theoretical construct it is supposed to test (Jonsson and Svingby, 2007; Moskal and Leydens, 2014). A construct is deemed valid when the assessment provides "legitimate indication of the skills that have to be measured" (Moreno, 2010). For this research, the main outcome to measure is problem solving skills. Therefore, the PPR designed must measure the students' ability to identify and plan the solution with the purpose of solving the given problem.

For this, an expert, who was the senior lecturer in the Educational Test and Measurement Department, and in the rubric design was selected to review the construct of the Problem solving Process Rubrics (PPR) in terms of its criteria, levels, and descriptors. The validation process began after the rubric content was checked and validated. Table 3.16 shows the validation cycle before the first version of the rubric was produced.

Table 3.16: Construct Validation Experts and Cycles

No.	Expert	Experience	Types of Validation	Validation Cycle
1.	Expert C	Senior Lecturer Test and Measurement Department, Faculty of Education (22 years)	Construct Validation	2 times

The researcher used the qualitative method of "expert review" to validate the PPR, as the value of the comments from the experts after review helped the researcher better understand the variables that influence the rubric design. Besides that, the comments on the rubric's design in which the expert did not agree on was then corrected.

3.10 Verification From Industry

The validation of the rubrics' design was important but, the most crucial ones was the feedback or verification from the real engineering people who did the engineering works everyday. In this study, in order to verify whether the PPR's content which include the problem solving processes (obtained from the PB Lab course) were align with the problem solving processes occurred in the real engineering industry, three experience engineers from three different company and specialization have been choosed. A complete checklist included the problem solving processed assessed in the PPR, with a Yes-or-No scale, was given to the engineers to be rated whether the processes happened in their real workplace.

This verification process have been done after the final PPR have been produced by researcher in Phase III. An email consists of the details objective of the checklists were also been given to get their permission and comfirmation. The details of the engineers were as below in Table 3.17:

Table 3.17: Details of the Engineers

No.	Engineers	Position/ Specialization	Company Name	Working Experiences
1.	Engineer A	Engineer / Network Management Operation	Telekom Malaysia Berhad	8 years
2.	Engineer B	Engineer/ Construction	X-Job Sdn Bhd	6 years
3.	Engineer C	Engineer/ Manufacturing	Intel Corporation	6 years

3.11 Conclusion

This chapter discussed in detail the case study approach used in this research. The three phases of this study included (a) Phase I: Identification of Problem solving Components in PB Lab course, (b) Phase II: Development of Problem solving Process (PPR) Rubrics, and finally, (c) Phase III: Validation of Problem solving Process Rubrics (PPR). The description of data collection methods used in each phase were highlighted along with the techniques of data analysis involved such as documents analysis and thematic analysis technique. The summary of the research procedures used in this study was also presented in the form of an operational framework in Figure 3.6. Besides that, the strategies used by the researcher to ensure the quality of the qualitative data, as well as the process of the PPR validation were discussed.

To better understand the analysis and the development of the PPR design, the results and discussion sections were divided into three chapters: Chapters 4, 5, and 6, based on the three research phases of this study:

a. Phase I: Identification of the problem solving process that occurred in the PB Lab course.
b. Phase II: Development of Problem solving Process Rubric (PPR) design
c. Phase III: Validation of the Problem solving Process Rubric (PPR) design.

CHAPTER 4

RESULTS AND ANALYSIS OF PHASE I

4.1 Introduction

The process in developing the rubric is very important to make sure it is valid, reliable, and truly measures the students' outcomes. There are three phases such as Phase I, Phase II and Phase III that have been gone through by resaecher in order to develop the PPR in this study. So, first and foremost this chapter provide results and analysis of research question for Phase I of the research methodology which thoroughly presented the main learning outcomes assessed, as well as the qualitative analysis implemented in determining the valid criteria of learning outcomes of the Problem solving Process Rubrics (PPR).

4.2 Phase I : Identification of Problem solving Process that Occur in PB Lab Course

As stressed by Mertler (2001), the process of rubric development began by defining the main learning outcomes needed to be assessed. Next, after the learning outcomes were determined, the specific observation attributes that students demonstrate in learning process was also identified. For this research, problem solving skills were selected by the researcher as key learning outcome to be assessed. The need of this outcome is stated clearly in the PB Lab course outcomes

(CO1 and CO2): "students must be able to identify, formulate, investigate, and synthesise information to solve complex engineering problems independently by relating theories and concepts discussed in lectures and information obtained from other learning resources".

For that purpose, the content of problem solving rubric must be valid and should represent the right problem solving skills it intends to measure. After problem solving skills were chosen as the outcome assessed, the second stage of Mertler's (2001) rubric development is to determine and identify the specific observation of students' attributes related to the outcomes was implemented. Here's come the main objective for Phase I of this research which is to identify the problem solving strategies during the PB Lab course activities to be included in designing the Problem solving Process Rubric (PPR). At this stage, the researcher identified the students' demonstrated attributes according to the learning process during PB Lab activities. By observing the learning process in the PB Lab course the researcher was able to determine the problem solving strategies which included the process that students take in solving problem (Ruhizan et *al.*,2012) in the PB Lab course. These processes were then inculcated in the PPR design in Phase II.

4.3 Data Analysis

There are two qualitative data which have been collected and analysed in Phase I. The data were as follows:

a. Unstructured Observation Field Notes (Data set 1)
b. Face-to-face Interview Transcripts (Data set 2)

The comprehensive analysis and results from Phase I qualitative data collection were presented and discussed in the following section.

4.3.1 Analysis of the Observation Data

Observation has been used by many researchers to interpret behaviour, attitude, facial expressions, and other non-verbal indication in many studies (Potter, 1996). Thus, in this research, the observation method provided rich information to identify and gain insight concerning the problem solving strategies occured in the PB Lab course that can be included in the Problem solving Process Rubric (PPR) design. The researcher thoroughly observed and recorded the PB Lab activities for three hours in each lab. Therefore, to ensure that the observation data were effectively recorded, "field notes" and "video recording" were used.

Besides that, in Phase I, only the PB Lab course under Bachelor of Engineering (Electrical) (SKEE) was chosen for observation, as it is the main programme in FKE. Four groups of SKEE students (Groups A, B, C and D) were formulated, with three to five students per group and one PB Lab facilitator. Every group was observed by the researcher from the first week until the fourth of the PB Lab's 12-week course, which was from November until December 2012. The observation was also done in two PB Labs: Advance Power Laboratory (APL) and Power Electronic Laboratory (PEL), both of which are under the Bachelor of Electrical Engineering (Power) (SKEE) programmes. In addition, the participants involved in this observation were selected using the purposeful sampling, which was proven to be the most suitable sampling method to provide the data essential for a qualitative study (Ary *et al.*, 2014). Thematic analysis technique (as explained in Chapter 3) was later applied by the researcher to analyse the observation data. Figure 4.1 shows the steps the researchers applied in analysing the observation data using thematic analysis.

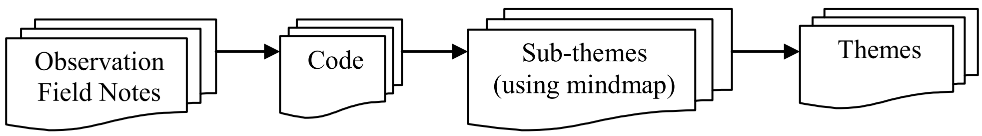

Figure 4.1: Thematic Analysis Applied in Analysing Observation Data

Based on Figure 4.1 illustrated on how the researcher analyse the collected observation data. Within three hours in the PB Lab course, all the observation data have been recorded using “field notes table”. The templates of the fieldnotes’ table have been prepared by researcher before entered the lab by referring to the field notes’ templates proposed by Creswell (2012). This table helps the researcher to identify and sort the relevant codes appear in the observation description. Refer to Appendix A for the example of the field notes table. In this phase, the codes are presenting the problem solving strategies which is the process that leads the students in solving problem in the PB Lab course. Besides that, to guide the researcher’s observation and in determining the code, the problem solving process model proposed by Woods *et al.* (1997) as below have become a guideline:

1) I can
2) Define problem
3) Explore problem
4) Plan the solution
5) Do it
6) Look back

This theory-driven strategy allowed the researcher to analyse the data based on certain theories or concepts (Anderson, 1993). The Woods’ problem solving process model helped the researcher to focus only for the relevant description of the field notes. The observation description that presented the problem solving process will be highlighted and extracted as a coded. Refer to Appendix B for the example of the observation description obtained. However, in this study there are 4 field notes that have been gathered from 4 groups of students. At first, each of the field notes will be analysed individually until the sub-themes for each groups identified. Figure 4.2 presents the examples of the sub-theme-generating mind-maps based on identified codes.

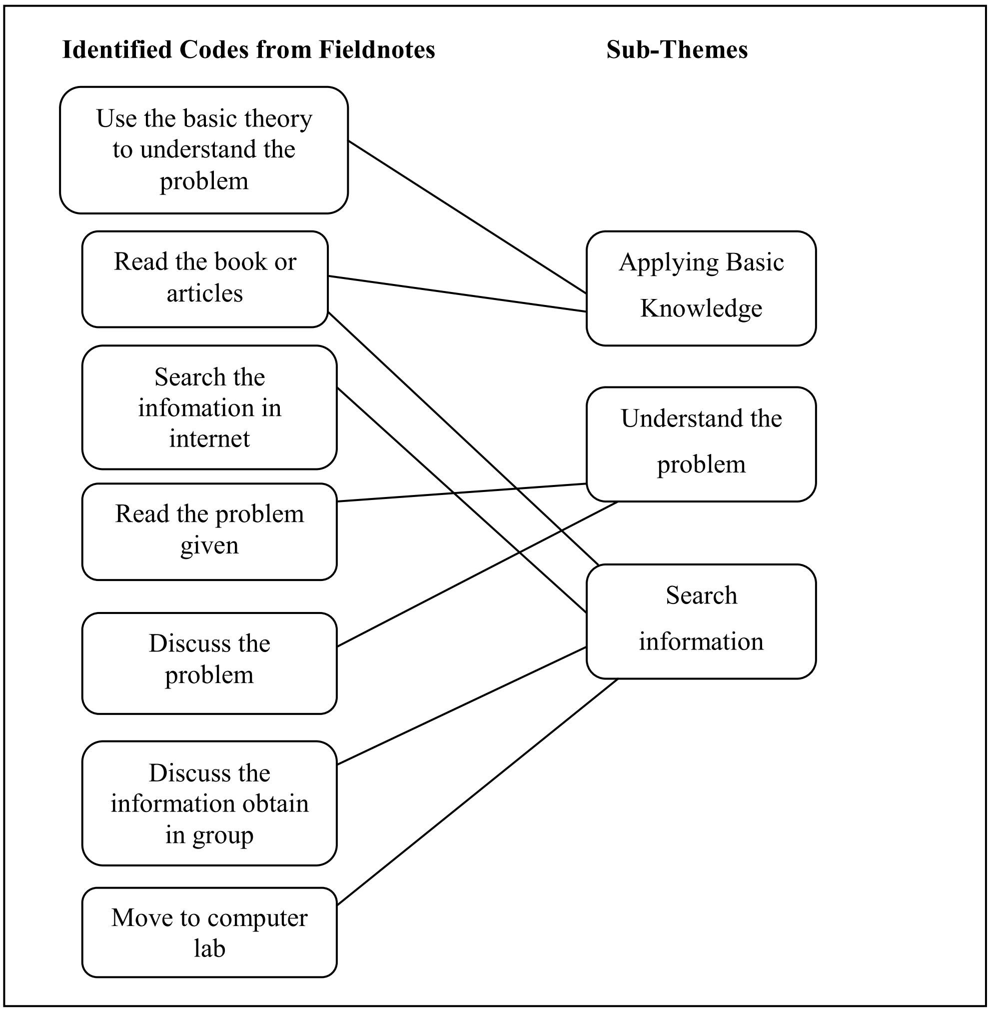

Figure 4.2: Examples of the Sub-theme-generating Mindmaps for Group A (Week One) Fieldnotes

Figure 4.2 shows the relevant coded which have been extract from field notes description of Group A for the first week of PB Lab course. Some codes was overlapping and this leads to identified sub-themes. Then, after all sub-themes for each field notes identified, all the sub-themes under four observation field notes will be reviewed and refined in determining the main themes of the observation data. Normally, at this stage, it can be seen that there are some sub-themes under certain field notes were correlated and did not correlated. So, the refining and reviewing of the sub-themes is needed at this stage in order to get the main themes of data (Braun and Clarke, 2006). To facilitate the process of correlating the sub-themes for each field notes, the researcher compared them using the "table-form" method. Table 4.1 shows the example on how the researcher compare each of the sub-themes under each field notes using table form and this process leads to the development of the main themes of this observation data. Specifically, the overlapping sub-themes for each groups have been determined by researcher manually.

Table 4.1: The Sub-themes and the Themes Identified in Observation Data

Lab/ Groups / Weeks	Sub-themes				Themes
	Advance Power Laboratory (APL)		Power Electronic Laboratory (PEL)		
	Group A	Group B	Group C	Group D	
Week 1	Understand the problem given	Understand the problem given	Understand the problem given	Understand the problem	
	Applying basic knowledge	Applying basic knowledge	Restate the problem	Applying basic knowledge	Understand the Problem
	Search information about the problem given	Distribute the task	Apply basic knowledge	Share information with team members	
	Share ideas/information with team members	Identify the component or devices	Search relevant information	Refine the problem	Information Searching
	Restate the problem given	Search the information	Share the information with team members		Application of Knowledge
	Distribute the task	Share the information with team members	Define the problem clearly		
		Interpret the information obtained			
Week 2	Plan the procedure	Plan the procedure	Search information	Share the information with team members	Plan the Solution
	Identify the devices or components	Search the relevant information	Share the information with team members	Search the relevant information	Devices /Component Recognition

	Understand the devices function	Identify the devices or components	Planning the solution	Design the simulation	
	Design the simulation	Share the information with team members	Select method to solve the problem	Apply basic knowledge	Information Searching
	Identify the connection to be made	Understand the problem	Apply basic knowledge	Define the simulation problem	
	Search information	Apply basic knowledge	Distribute the tasks	Interpret the simulation results	Application of Knowledge
	Determined data to be measure	Search information	Identify the devices or components	Identify the devices or components	Implement the Plan
	Interpret the simulation result	Undertand the devices function	Identify the connection to be made	Understand the devices function	
		Sharing ideas with team members	Understand the devices or component function	Sharing ideas with team members	
		Identify the connection to be made	Set up connection	Identify the connection to be made	
		Set up the devices connection		Set up the devices connection	
		Check the devices connection		Collect data from the devices	
				Check the devices connection	
				Identify the connection problem	
				Troubleshoot the connection	
	Set up the connection	Set up connection	Set up connection	Interpret the results	Implement the Plan
	Collect data from the devices connection	Check the connection	Check the connection	Prepare for presentation	
Week 3	Interpret the result obtained	Collect data from the devices	Collect the results from the devices		Collect and Analyse the Data
	Identify the connection problem	Check the connection	Identify the connection problem		Check the Plan
	Identify the results obtained	Identify the connection problem	Troubleshoot the connection problem		

		Troubleshoot the connection problem	Determine data to be measured		
		Interpret the result obtained	Collect the data from the devices		
			Interpret the result obtained		
			Apply basic knowledge		
			Collect the results from the devices		
			Interpret the results obtained		
Week 4	Present the problem given	Present the problem given	Share information with team members	Present the problem given	Present the Results
	Explain the procedure or method used	Explain the procedure or method used	Explain the procedure or method used	Interpret the result obtained	
		Interpret the result obtained	Interpret the result obtained	Apply basic knowledge	
			Apply basic knowledge		

Based on Table 4.1 shows that there are nine themes which represented the problem solving processes discovered from observation data of PB Lab activities from the first week until the fourth. It can be seen that the process in both laboratories were mostly the same, though the projects given to the students were different.

The same process were clearly apparent at the beginning of the PB Labs (APL and PEL) in the first week, where the students receives the project, followed by a short introduction given by the facilitators regarding the project, the assessment, and the time frame. The observation also reflected that most facilitators provided at least one to two hours for the students to search for information regarding the project and identify the issues and main objective of the project. In this time, the students actively discussed with their team before independently searched for information on the internet, and in books or journals to understand the project and subsequently establish a list of solutions to solve the problem or complete the project. Overall, it can be summarised that problem identification is the main process to happen in the first week and this slightly differed from the activities in the second week.

Following the first week, the students continued to identify the relevant information from various sources to guide or as references for them to develop procedures or steps to solve the project. Although some students were still unclear with the project given, they cooperated in planning the design or coding with some facilitation from the PB Lab facilitator. Based on Table 4.1, it was seen that all the groups in PB Lab course had already begun planning and designing the connection tools or developing the code. However, only one group in PEL Group D successfully planned, designed, troubleshot, and completed the design connection until they obtained the desired results. The group was a step ahead from the other groups, as the information they gathered from various sources to solve the problem directly led to the solution of the problem. For other groups, following the process of planning and designing the solution in the second week, students proceeded to set up the experiments or run the software to acquire an output in the third week. Most students have already understood the requirements to solve the project and now struggled to design and obtain the results for interpretation. They were able to identify, relate and apply the fundamental electrical knowledge practically when designing the circuit or developing the coding. When the students applied the concepts they have learnt in class to solve the given problems in the laboratory, this was when mental processing occurred. Besides that, when collecting the data or the output of the experiments in different forms such as graphs, signals, and numbers, the students underwent another mental process, whereby they attempted to interpret the results acquired in the third week, followed by the presentation of a strong solution in front of the panels in the fourth week. In short, these activities showed that plenty of individual thinking processes were involved during PB Lab.

After examining the observed PB Lab activities, the results showed that problem solving process occurred in the PB Lab course, as the students faced many situations where problem solving skills were required of them from the first week until the fourth week of the PB Lab course. They had to understand, define key issues of the problem, and develop plans or strategies to solve the problem until they reach a possible solution. Mourtos *et al.* (2004) explained that problem solving is a process to obtain the best solution to an unknown or a decision, which is subject to constraints. A well-structured or an ill-structured problem is given to students to be solved and they will attempt to understand the given problem and discuss with their group members. Eventually, they will arrive at several proposed solutions. This form of learning activity is actually a thinking process or steps that students apply to solve problems. Sometimes, this process of solving problems occurs naturally within the students, although the final state of the problem remains unclear. This statement is similar to the definition of problem solving proposed by Woods *et al*. (1997), who defined that problem solving in an engineering context is the “process used to determine the best answers to an unknown, or a decision subject to some constraints”. The term “process” is defined as the step-by-step process that students must undergo to solve the problems, whereas the terms “best answers” and “subject to some constraints” emphasised that in solving real-world problems, the students will face challenges that lack of information and resources. Based on the limited information, students will then be required to think and apply the best solution to get possible answers.

The following excerpt from observation field notes represented as examples of the themes obtained in more details:

1. Theme #1: Understand the Problem

Based on the observation, all the groups in APL and PEL PB Lab course started by understanding and identifying the main issues and the objective of the problem given. According to Moreno (2010), the first step in the problem solving model consisted of problem-identification. This is the most important step because students will read the problem and try to interpret and restate it in their own words. The following are several excerpts taken from the observation field notes which showed the process.

> The facilitator and the students discussed the problem given together. Then, the students discussed with their group members in front of the facilitator.
>
> (Observation W1 Group A, 19 November 2012)

> The facilitator …… asks them about their understanding on the problem given,one student at a time.
>
> (Observation W1 Group B, 19 November 2012)

> The students got problem in understanding the problem so, it can be seen that they discussed the problem each others.
>
> (Observation W1 Group D,19 November 2012)

The above excerpt clearly showed that the main activity in PB Lab in the first week was problem-identification. During this first week, each students tried to understand the given problem clearly with the facilitation from the facilitators. Discussion with the group members also helped students individually to understand the given problem clearly. These interaction with people surrounding such as facilitators or group members can lead student to construct knowledge or understanding in their mind (Gauvain, 2001); as explained in cognitive constructuvism theory in Chapter 2. Thus, this was strong evidence that the "understand the problem" took place during the first week of the PB Lab course.

2. Theme #2: Information Searching

As shown in Table 4.1 for week one and week two, it was seen that several activities led and supported the students to successfully understand and identify the problem. One of them was by searching information. According to Fogler *et al.* (2008), the process of gathering or defining the information from various materials will lead the students to better understand the problem given.This "information searching" process was identified happened especially in week one and week two of the PB Lab course. In order to undertand the problem and plan the strategy to solve the problem, additional information from various sources such as from journal, articles, books or internets are needed as a supported data. The following are several excerpts taken from the observation field notes which showed the process happened in PB Lab:.

> It can be seen that student still can't understand what they need to do with the problem, so they move to computer lab and find information from the internet regarding the problem given. After an hour, this group comes back to the lab and starts a discussion with their group mates about what information they obtained.
>
> (Observation W1 Group A, 19 November 2012)

> Some students brought books and read articles from e-journals stored in their laptop to study the problem.
>
> (Observation W1 Group D,19 November 2012)

> Student sat in the respective group. They seemed to understand some references that they are using. Three students brought laptops while the rest read and wrote something on paper. Most of them are reading journal on their laptops.
>
> (Observation W2 Group C, 26 November 2012)

3. Theme #3: Application of Knowledge

The following are several excerpts taken from the observation field notes which showed the "application of knowledge" process happened in the PB Lab activities.

> The facilitators briefs the students about the concept of Unipolar and Bipolar electrical circuit. Then, the facilitators let the students discuss among their group members whether or not the concept can be applied to the problem given.
>
> (Observation W1 Group D, 19 November 2012)

> The facilitator asked the students some electrical fundamental knowledge. Two students answered the question. Then the facilitator asked them to explain how they apply the formula.
>
> (Observation W2 Group C, 26 November 2012)

As shown in the transcription above, applying the previous knowledge learned in the class in order to solve the PB Lab course problem are normally happened in week one and week two of the PB Lab. Students tried to revise the basic knowledge or concept which related to the problem given. Within this period, the students are critically think and try to apply the knowledge in order to solve problem.

4. Theme #4: Plan the Solution

Another activity discovered in PB Lab course related to the problem solving process was planning the procedures or strategies to solve the problem. The examples of the activities taken from the observation data are as follow:

> The facilitator asked the students on what they have found. One student showed the simulation that they have done. While the student demonstrated the simulation, the facilitators kept asking the students: "What's next?".
>
> (Observation W2 Group C, 26 November 2012)

> Three students were designing the circuit. One student drew the circuit while others were discussing.
>
> (Observation W2 Group D, 26 November 2012)

> Three students tried to draw the circuit connection on paper and tried to match it with the circuit on the trainer.
>
> (Observation W2 Group B, 26 November 2012)

According to Bloom and Broader (1950) and Simon (1980), planning the strategies is one of the most important process in solving problems. The students should spend more time planning the solution and ask triggering question to develop ideas: “What do you want?”, “How can you get this problem?”, “How can you find this kind of unknown?”, and “From what data can you derive this kind of unknown?” (Polya, 1985). Mourtos *et al.* (2004), reported that during this phase, students normally begin to draw the concept related to the problem, write the related equations, and develop prior fundamental knowledge. The same activity was also discovered while observing the activities in the PB Lab course. They: (a) searched for information from various sources; (b) identified the fundamental knowledge; and (c) acquired the concept and wrote the equations related to the problems. Aside from that, the students also started to draw and write the ideas came up with to solve the problem.

5. Theme #5: Devices and Component Recognition

The fifth problem solving process identified based on the observation data was the devices and component recognition. Based on the observation trancscription, this process happened to all the students’ group.

> The students started searching and identify devices that they wanted to use.
>
> (Observation W3 Group A, 3 Disember 2012)

> The students got the component that they wanted to use and they started to discuss the function of each component.
>
> (Observation W3 Group C, 3 Disember 2012)

> The facilitator discussed with the student and they went to the next room to check on the devices that will be used.
>
> (Observation W2 Group D, 26 November 2012)

Based on the observation transcription above, it was discovered that students will started to identify and understand the devices or the components that they have to used on week two or week three. It is important to highlight that some students have to design the connection of the components using software then through the results of it, they will transfer it to connect to the actual connection using real devices in the laboratory. This is the important process before they proceed to implement the real connection. The value such as the capacitors, voltage used must be suitable to avoid the connection problem during the implementation phase.

6. Theme #6: Implement the Plan

The third process discovered from the observation was that the students began to implement their plans. If the solutions were properly planned, it will be easier for them to conduct the strategy selected during this phase. According to Fogler *et al.* (2013), during this phase, nine things should be monitored. One of them was to construct the experiment to discover whether the solution selected will work or not. The following excerpt was taken from the observed activities that involved implementing the solution phase in the PB Lab course:

> Two students connected the node on the trainer and completed the procedures.
>
> (Observation W2 Group A, 26 November 2012)

> The students have completed their simulation. They were trying to transfer the circuit connection (like they design in the simulation) into the real trainer.
>
> (Observation W2 Group D, 26 November 2012)

> The students started the laboratory session by directly conducting the experiments (check the circuit on the board that they did during week two).
>
> (Observation W3 Group C, 3 Disember 2012)

This phase clearly showed that the students implemented what they have planned to solve the problem. They identified and defined the desired tools to use, write the coding and try to run the software to get the results. These are the most straightforward steps in problem solving process if the students have the appropriate strategies to reach the solution (Moreno, 2010).

7. Theme #7: Collect and Analyse the Data

Next, the theme identified was the process of collect and analyse the data. Normally during this phase, each group of student will gathered the results that they obtained based on the devices connection. Then, the results will be compared with the results from the software or the calculation that they did. This is the important phase which proved that the solution that they took was right and solve the problem given. The following excerpt was taken from the observed activities that represented this phase:

> The students checked the circuit connection and tried to get the results using oscilloscope.
>
> (Observation W2 Group D, 26 November 2012)

> The students compared the results that they obtained from the simulation with the results from trainer.
>
> (Observation W2 Group B, 26 November 2012)

> The facilitator instructed the students to draw the graph and explain it to him later on.
>
> (Observation W3 Group C, 3 Disember 2012)

8. Theme #8: Check the Plan

Checking solution is another process that took place in the PB Lab course. This is among the hardest step in the problem solving process and involved several thinking processes to interpret whether the results obtained made sense or not towards the problem. In the PB Lab, the checking, or troubleshooting, phase involved several thinking processes, discussion among group members and facilitation from the facilitators to obtain the best solution. The following are the examples of several excerpts taken from the observation data:

> The facilitator came to the students and checked their circuit that they have connected on the trainer. Then, the students tried to troubleshoot the circuit until the circuit is completed and they got the results.
>
> (Observation W3 Group C, 3 Disember 2012)

> The circuit connection made by students was wrong, so they had to re-do it.
>
> (Observation W3 Group B, 3 Disember 2012)

> The students compare the results that they obtained from the simulation with the results from the trainer.
>
> (Observation W3 Group D, 3 Disember 2012)

> The facilitator checks the students' experiment results and asked their understanding about the obtained results.
>
> (Observation W3 Group A, 3 Disember 2012)

Based on the observation, it was seen that during this phase, students applied all of the information they acquired from the facilitators, graphs, simulation results, and from their prior knowledge to interpret the achieved output. If the output or the results were wrong and unable to solve the problem, the students will troubleshoot the design or rewrite the codes again. Thus, this process led to higher thinking skills, as they were required to interpret the results and compare it with the theory.

9. Theme #9: Present the Results

The final problem solving process discovered after the solution-checking in the PB Lab course was the evaluation of the solution. This process occurred during the fourth week, when the students presented their solution in front of the panels. During this phase, the panels evaluated their solution to identify any mistakes. The examples of the activity are as follow:

> The students began the presentation by introducing the problem that they obtained, followed by the method that they used.
>
> (Observation W4 Group D, 10 Disember 2012)

> The facilitator asked the students questions regarding the methods that they used. The students seemed difficult to answer the question.
>
> (Observation W4 Group B, 10 Disember 2012)

> The facilitator provided comments to students to indicate that their results are not reaching satisfactory level.
>
> (Observation W4 Group C, 10 Disember 2012)

> While students were presenting their project, the facilitator asked them some theories related to the project but the students could not answer it.
>
> (Observation W4 Group C, 2012)

Based the above excerpts, most of the facilitators evaluated the students' solution based on the method that they use, the obtained results, and their understanding of the fundamental electrical knowledge behind it. However, to enhance the students' problem solving skills, the educators should evaluate not only the precision of the solution, but also the process of finding the solution (Zimmerman, 1990).

In conclusion, there are nine main themes have been discovered from the observation data which are: (a) Understand the problem, (b) Information searching, (c) Application of Knowledge, (d) Plan the solution, (e) Devices and component recognition, (f) Implement the plan, (g) Collect and analyse the data, (h) Check the plan and (i) Present the result. These themes have been gathered using the theory-driven strategy where the Woods *et al*. (1997) problem solving process model have been refered as a guideline in identifying the process of solving problem in PB Lab course.

4.3.2 Analysis of the Interview Data

To support the observation data, face-to-face interview sessions were conducted to verify the observed problem solving strategies in the PB Lab course. Seven participants who are PB Lab facilitators (P1, P2, P3, P4, P5, P6, and P7) from various electrical engineering fields were interviewed. P1 and P2 were interviewed on December 2012, while P3, P4, P5, P6, and P7 were interviewed on November 2013. The semi-structured interview that involved a series of open-ended questions were implemented based on research objectives (refer Appendix D). The following questions were asked during the interview sessions to determine the facilitators' feedback:

"How do you facilitate and conduct the PB Lab course from week one until week four?"

Based on the interview question, the objective was to determine the manner in which the PB Lab facilitators conducted the course. The problem solving strategies which is the process in solving problem that occurred during the facilitation activities were identified according to the response. In order to analyse the interview data, the same steps applied in analysing the observation data also applied for interview data. The description of the interviews data which have been transcribe from the video recorder are included in the table-form manually. Then, based on the interview description, the relevant codes (guide by Woods *et al*. (1997) models) have been identified and mind-map in order to get the sub-themes of the data. Figure 4.3 illustrate the example of the identified codes and their sub-themes for participants one (P1).

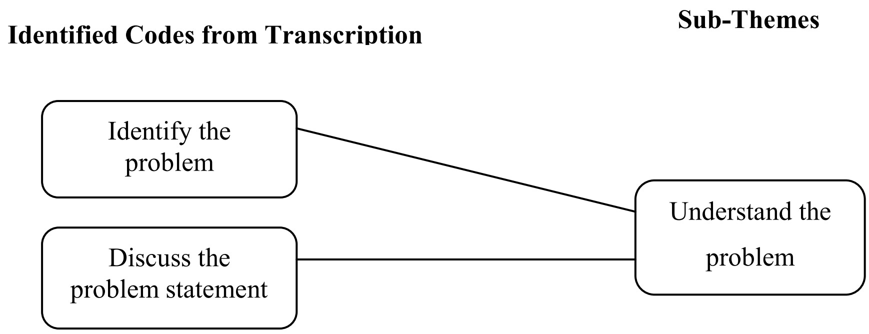

Figure 4.3: Examples of the Sub-theme-generating Mindmaps for P1 Interview Data

Table 4.2 shows the example on how the researcher compare each of the sub-themes mentioned by participants using table form and this process leads to the development of the main themes. Specifically, the overlapping sub-themes for each participants have been determined and differentiate by researcher manually.

Table 4.2: The Sub-themes and the Themes Gathred from Interview Data

Participants / Weeks	Sub-themes							Themes
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	
Week 1	Understand the problem	Identify the problem	List out the objective that must be achieve	Understand the problem through student pack	Identify the problem	Identify the problem	Identify problem	Problem Statement and Problem Objective Identification
	Identify the problem statement	Applying Basic Knowledge		Explain the devices function	Search information	Understan d the equation given		

Week 2	Prepare the procedures	Plan the solution based on theory	Proceed to procedure planning	Devices and hardware preparation	Design the hardware	Write and plan the code	Preparee the code	Procedures, code and measured variable planning phase
	Prepare the equipment			Samples development	Understand the devices function			
Week 3	Conduct experiment	Connect the circuit	Start the experiment	Conduct experiment	Connect the circuit	Run the codes	Run the codes	Implement the experiment/ design Check the results
	Check the device connection	Troubleshoot the devices connection	Prepare the devices	Analyse the data	Determine the results obtained			
	Collect data and analyse							
Week 4	Present the results	Present the results	Present the results	present the solution	X	Present the solution	Present the results	Present the Results

Note: X means not mentioned by facilitator

Based on Table 4.2, five main themes have been determined in the interview data which were differ to the results identified from the observation data. The following excerpt from interviews transcription represented as examples of the themes obtained in more details:

1. Theme #1: Problem statement and problem objectives identification

Based on Table 4.3, six PB Lab facilitators (F1, F2, F4, F5, F6, and F7) clearly mentioned that the problem solving process identified in week one is the collective discussion of the problem and identification of the problem statement after the students were given the problem to solve. The following is an excerpt from F1:

> "On the first PB Lab meeting, they will try to understand the problem and identify the problem statement in order to better understand the problem. Then, I will give a short brief to the students about what will be assessed in this PB Lab course…… At the end of the first PB Lab session, I will revise again what they understand about the problem and facilitate what they have done and their progress in week one."
>
> (Participant F1)

The explanation was also similar to what was addressed by F2:

"During the first PB Lab meeting, I will provide the problem to the students, and based on that particular problem, they have to determine the problem objective. Normally, I will provide 15 minutes to 30 minutes for them to think and search on how to solve the problem. After that, I will come to them and ask what they understand about the problem…..If they have learned the fundamental knowledge about the problem, I will advise them to revise the topic in order to help them to understand the problem."

(Participant F2)

"On week one, students will obtain the problem to solve. Then they brainstorm it and search the related information about it from the internet They will identify the related journal paper".

(Participant F5)

The above excerpts indicated the facilitators' feedback on how the activities in the PB Lab course were conducted during the first week. It was observed that the "understanding the problem" phase was discovered then. With the guidance of the facilitator, the students identified the problem statement and the objectives. Several activities or processes that took place in the PB Lab mentioned by the facilitators led the students to understand the problem. These processes were: (a) revising the previous topic; (b) brainstorming; and (c) searching for information about the problem. These activities helped students to better understand the problem given.

2. Theme #2: Procedures, Code and Measured Variable Planning Phase

The second process stressed out by the facilitators during the interview was that the students started planning for the procedures or codes to solve the problem.

Besides that, the students also determined the key variable to measure to help them collect the results or determine the necessary output. This was determined based on the following excerpt:

> "Supposedly, on week two, student should already understand the problem given and they have to start to prepare the procedure, types of equipment that they want to use and its configuration. At the end of the meeting, I will reflect back what they have done on week two."
>
> (Participant F1)

> "On week two, supposedly students already understand and know how to tackle the problem. They should already have the outline. I will asked them how they want to solve the problem, what theory that they used, what kind of software that they want to used and then, they will setup the experiment based on the theory that they choose. I will facilitate them."
>
> (Participant F2)

> "My lab is more on designing the hardware on week two. Student will find out what they are going to measure and what the suitable tools to use. Then, students will start searching the datasheet and apply it to solve the problem."
>
> (Participant F5)

> "On week two, students have to present the information that they have found from previous week. Then, they started to write the code in order to get the output that they have to obtain."
>
> (Participant F6)

Based on the facilitators' views, it was shown that in the second week, students understood the problem better and have already determined an outline to solve the problem. This process was obtained from F1 and F2's comments. Moreover, several important activities to plan the solution were discovered from the interviews. They included: (a) identifying the use of hardware or software tools; (b) applying the fundamental electrical knowledge; and (c) developing the procedures or codes. These activities were clearly mentioned by F1, F2, F5 and F6.

3. Theme #3: Implementing the Experiment or Design

The third problem solving process identified based on the interview transcripts was the implementation of the experiment and hardware or software design. According to the facilitators' responses, this process happened in the third week. This was determined based on the following excerpt:

> Then, on week three, student will started the experiment and the technician will facilitate them in order to make sure the connection that they build up is correct.
>
> (Participant F1)

> The students already knew what to do on PB Lab week two and they just proceed the work on week three meeting. They will connect the devices on week three and normally the connection will have a problem.
>
> (Participant F2)

> The students will proceed with the experiment after the procedures that they design have been approved. Then, they will start searching the devices to use.
>
> (Participant F3)

Based on the facilitators' explanation, it was discovered that after the planning phase, students implemented the established procedures or designs. This can be seen from F1, F2 and F3's statements, whereby it was reported that student started to "connect the devices" and "set up the experiment" on week three. Besides that, there was also a "looking back" phase where the facilitator check the students' connection and output to justify the precision of their results. During this phase, students compared the hardware or the software results they obtained with fundamental knowledge acquired in class.

4. Theme #4: Check the Results

Check the results is another important phase in the PB Lab course. This phase involved several thinking processes to interpret the results and during this phase the PB Lab facilitators were responsible to facilitate and guide the students to reflect back and review the results obtained. Besides, according to the facilitators' responses, this process usually happened in the third week after the students implemented their plan. This was determined based on the following excerpt:

> Normally, I will look at and check their experiment results. At the end of week three meeting, they must reflect back the output that they got, and what can be conclude based on the results.
>
> (Participant F1)

> I will ask them one by one and they have to troubleshoot the circuit until got the correct results.
>
> (Participant F2)

5. Theme #5: Present the Results

After a thorough analysis of the results obtained, the students presented the results or outcome in front of the panels. This is the last process of problem solving which were discovered based on the interview excerpts. By looking at the statements from F2 and F4, it can be deduced that during the fourth week of the PB Lab course, students have already finished their experiments or design and they presented the outcome. The question-and-answer session was also held during the presentation phase.

> After that, they just present their results.
>
> (Participant F1)

> On week four, the student will present and they will take note comments from the panels. At the end of the session, they will be asked to prepare a report.
>
> (Participant F2)

> The student will present the solution and they will be asked during the presentation on week four.
>
> (Participant F4)

By looking at the statements from F2 and F4, it was observed that, during week four of the PB Lab course, students have finished their experiments or design and proceeded with the presentation of their results. As the question-and-answer session was also conducted during this presentation phase, students must clearly understand what they have done to answer the panel's questions.

4.4 Results and Validation

The results obtained from the observation and interviews clearly showed the occurrence of the main themes that represented as problem solving process in the PB Lab course from the first week until the fourth. Nine sub-themes were discovered by the researcher while observing the lab activities and five sub-themes were determined based on the facilitators' responses during the interview sessions. Table 4.3 shows the results of triangulation between the observation and interview findings:

Table 4.3: Phase I Themes

Week	Themes	Sub-themes (Observation data)	Sub-themes (Interview data)
Week 1	Problem Identification	• Understand the Problem • Information Searching • Application of Knowledge	• Problem statement and problem objectives identification
Week 2	Project Planning	• Plan the Solution • Devices /Component Recognition • Information Searching • Application of Knowledge • Implement the Plan	• Procedures, Code and Measured Variable Planning Phase
Week 3	Implementing Engineering Design	• Implement the Plan • Check the Plan	• Implementing the Experiment or Design • Check the Results
	Project Analysis	• Collect the Data • Analyse the Data	
Week 4	Evaluate the Solution	• Present the Results	• Present the Results

Based on Table 4.3, five themes which reflect the problem solving processes discovered from the observation and interview data gathered from the first week until the fourth. These processes were: (a) Problem identification; (b) Project planning; (c) Implementing engineering design; (d) Project analysis; and (e) Evaluating the solutions. In order to validate the determined problem solving process investigated by the researcher, measurement of Percent Agreement was been used by the researcher. The findings given by the triangulation of the observation and interview data were reported in Table 4.3. The results provided strong evidence that problem solving processes did occur among students in this course. Three PB

Lab facilitators, who were experienced in conducting the course and experts in the electrical engineering domain reviewed and validated these data.The experts completes the Form of Agreement (refer Appendix C) provided by the researcher and the results were analysed using the Percent Agreement measurement. Details on the experts have been reported in Section 3.8 (1). Figure 4.4 shows an example of Form of Agreement.

WEEKS	ITEMS	CODING	#	A	NA
Week 1	The facilitator and the students discussed the problem/project given together. Then, the students discussed with their group members in front of the facilitator.	Problem Identification *(discuss, problem/project given)*	1	√	
	The facilitator brief some concept about the problem presented to the students.	Problem Identification *(brief, concept, problem)*	2		√
	The students found the information by using the computers.	Information Searching *(computer , found information)*	3	√	

Figure 4.4: Example of Form of Agreement

This measurement method was used because the researcher was then able to identify the degree of agreement and give a simple estimation of reliability value between the raters (Hunt and Dentistry, 1977). Based on Figure 4.4 shows there are two column that has to be complete by experts. The column A is stand for “Agree” and the NA is stand for “Not Agree”. Experts need to complete this form by ticking either A (agree) or NA (not agree) for each the item. Specifically, the items are based on the description obtained from interview and observation that referring to the problem solving process. So, after the form completed, the percent agreement have been measured by making a table of the rating. For this study, there are three raters (R) so, additional columns for the combinations (pairs) of rates are needed: R1/R2 and R2/R3.

Hence, the value of Percent Agreement was calculated based on the mean of the agreement between raters. Finally, the results are shown in Table 4.4:

Table 4.4: The Percent Agreement Results

Raters	Percent Agreement (%)

Rater A vs Rater B	76.8
Rater A vs Rater C	83.8
Rater B vs Rater C	90.9

Based on the findings above, there was a reliable and high agreement between the raters. The Percent Agreement between raters A and B was 76.8%, while raters A and C resulted in 83.8%. Raters B and C acquired 90.9%. According to Multon, 2012), the accepted value for the Percent Agreement is 70%. The Percent Agreement achieved indicated that most raters agreed on the determined problem solving process that occurred in the PB Lab course from the first week until the fourth. It was clearly agreed upon of the five main problem solving process that occurred during PB Lab.

4.5 Conclusion

As discussed, the three phases that took place during this study were: (a) Phase I: Identification of the Elements of the Problem solving Process in PB Lab course; (b) Development of the Problem solving Process Rubric (PPR); and finally (c) Validation of the Problem solving Process Rubrics (PPR). Chapter 4 discussed the findings of Phase I. Two qualitative data collection methods and analysis were implemented to determine the problem solving process that occurred in the PB Lab course. The problem solving process model proposed by Woods et *al.* (1997) was used as a reference in determining these process. Four groups, each of which consisted of five students and one PB Lab facilitator, were observed and seven PB Lab facilitators were interviewed in this study. By using the thematic analysis technique, results from the analysis indicated that there are five main themes associated with the problem solving process in the PB Lab course activities as reported in Table 4.5. These process were also determined as one of the main factors that led to the enhancement of the students' problem solving skills in PB Lab context.

Table 4.5: Research Question 1 and Finding

Research Question	Findings
RQ1) What are the problem solving processes that occur during the PB Lab course activites?	There are five problem solving processes that identified occurred in the PB Lab course. The processes were: (a) Problem Identification (b) Project Planning (c) Engineering Design Implementation (d) Project Analysis (e) Solution Evaluation

CHAPTER 5

RESULTS AND ANALYSIS OF PHASE II

5.1 Introduction

After problem solving process in the PB Lab course been identified in Phase I, now, the Problem solving Process Rubrics (PPR) will be constructed in this Phase II based on Phase I results. As known, rubrics are scoring tools that are normally used with performance assessments. They include three important parts: (a) criteria; (b) descriptors; and (c) levels of students' performances. Each parts in the rubrics design must be clearly constructed in order to make sure the rubrics is valid and reliable. Nowadays, many rubrics have been designed and they can easily be found on the internet. So, from 1,000,000 to 13,000,000 rubrics uploaded on the internet, how to determine the best rubrics which are suitable for our context? It is difficult to answer this question because several rubrics have been designed for different contexts and they cannot be generalised to other contexts. Due to the foregoing reason, this chapter reports in detail how the Problem Solving Process Rubric (PPR) criteria, descriptors and level of performances has been developed, especially for assessing problem solving skills in project-based learning in laboratory course.

5.2 Phase II: Development of Problem solving Process Rubrics (PPR)

Phase II of this study involves steps 3, 4, 5 and 6 of Mertler's (2001) rubric development model which has been referred to in this study. Based on the Phase I results in Chapter 4, five problem solving processes occurred during PB Lab activities. These are the processes: (a) problem identification; (b) project planning; (c) engineering design implementation; (d) project analysis; and (e) solution evaluation. Specifically, these processes are determined in order to be included as the main criteria of the Problem Solving Process Rubric. Besides, the identified problem solving processes also help in guiding the researcher to select the sub-criteria and descriptors to be included in PPR's design. Some data have been gathered by the researcher during Phase II such as from interview II transcripts and documents. Besides, the results obtained Phase I also have been used in Phase II. In order to effectively report the step-by-step processes in constructing the PPR which have been done by the researcher, the discussions of this Chapter 5 are based on the second set of research questions (RQ2) of this study.

This phase focuses on three important parts of the rubric's parts: (a) Rubric's criteria; (b) Rubric's descriptors; and (c) Rubric's levels of performances. Table 3.7 in Chapter 3 presents the summary of the data collection and the objectives of designing the PPR's criteria, descriptors and levels for this study. All collected data for Phase II have been analysed thoroughly using the Thematic Analysis and Document Analysis technique; this is to ensure all of these qualitative data are aligned and triangulated to one another. The results obtained in Phase I (included five themes) are used in developing the PPR's construct. It is very important that all the criteria listed in PPR are aligned with the problem solving outcomes of the course. Finally, after the PPR has been constructed, the PPR version 1 is produced. The detailed discussions of the Problem Solving Process Rubric's criteria, descriptors and the levels developed by the researcher in this study are reported below. Specifically, the Problem solving Process Rubric (PPR) is an analytic rubric; it examines parts or characteristics of students' performances.

5.3 Criteria for Problem Solving Process Rubrics (PPR)

Rubric's criteria are one of the important parts in rubrics' design. As defined by Glatthorn (1999) criteria are the components of quality used in guiding the evaluation process. They specifically list all the qualities of students to be assessed and are aligned with the required learning outcomes (Arther and McTighe, 2000). As known, in this study, the problem solving skills have been chosen as the main outcomes to be assessed. The selection of these outcomes is due to the high demand from industries that prefer graduates with excellent problem solving skills. Besides, problem solving skills also are one of the critical skills which have been listed in the Engineering Accreditation Council (EAC) programme outcomes and PB Lab course outcomes. Consequently, it is essential for the criteria listed in the Problem Solving Process Rubric (PPR) to truly reflect problem solving skills, which the students must acquire. Several qualitative data have been gathered by the researcher during this study so as to combine and triangulate to develop the constructs and sub-constructs of the PPR's criteria. Specifically, the qualitative data gathered are extracted from the Phase I results (reported in Table 4.3), interview II transcripts (data set 3) and documents (data set 5). All of these data helped the researcher in constructing the PPR's main criteria and sub-criteria. Each piece of data collected is analysed and reported as below before it is triangulated and included in the first version of the PPR design.

5.3.1 Phase I Results

Previously, Chapter 4 has summarised five themes which represented the process of problem solving occurred during the PB Lab activities. The processes are:

a. Problem Identification
b. Project Planning
c. Engineering Design Implementation
d. Project Analysis
e. Solution Evaluation

The objectives of these data collection are formulated to identify the process of problem solving that occurred during the PB Lab course activities, to be included in the PPR's main criteria. It is important to determine these processes so that there are processes of problem solving occurring during the PB Lab activities. In this way, the PPR's criteria that have been developed will truly assess the learning outcomes that happened in the real PB Lab setting, and not merely evaluate those listed in the programme outcomes documents, which in fact may not happen in the real PB Lab activities. While observing the students in PB Lab course during Phase I, the researcher discovered that there were other process which happened that might contribute to the success of the main problem solving process in each of the PB weeks.

Specifically, based on Table 4.3, the identified themes were the main process of problem solving startegies occurred in PB Lab course. While other processes reported in Table 4.3 were the sub-themes under the observation and interview data. These sub-themes was also the problem solving process which have been discovered by researcher in leading the students to go through the main problem solving process each week in PB Lab course.

Specifically, the main problem solving process that occurred in week one is the Problem Identification process; it can be said that other process that happened in this week are one of the factors that might contribute to the success of this Problem Identification phase. It can be identified clearly based on the results of sub-themes reported in Table 4.3 shows other process done by students in week one. The process are:

a. Understand the problem / Problem statement and problem objectives identification
b. Applying Basic Knowledge
c. Information Searching

All of these process have been determined as the sub-themes by the researcher based on the observations and interview for week one. Normally, in week one, students have to define the problem statement by discussing it with the team members and PB Lab facilitator. In addition, in order to better understand the problem, students have to relate the given problem to the previous knowledge they had learnt during class. Apart from that, it can be seen that most of the students also searched for information in books, journals and internets, which are relevant to the problem. By looking at the positive impact of these processes in facilitating the problem identification phase in week one, these activities have been selected by the researcher as the Sub-process under the main process of Problem Identification for Week One.

In Week Two, there are five process happened among students which have been identified. The processes are:

a. Plan the solution / Procedure, code and measured variable planning phase
b. Applying previous knowledge
c. Information searching
d. Equipment/component recognition
e. Implement the solution

As determined, the main problem solving process that occurred in week two is “Project Planning”. During this process, normally, students discuss in a team and start planning the experiment procedures and determine the devices that can help them to get an output to solve the problem. In order to ensure the project planning phase is successful, all the five processes which have been discussed above must be implemented by students so that they can plan the project planning effectively. In assessing students’ skills in week two of PB Lab course, all the five determined process are included as sub-process under the Project Planning

Besides that, there are four process which had been determined in the third week of the PB Lab course. All of these process were identified to have contributed to the main processes of problem solving in Week Three-Engineering Design Implementation and Project Analysis. The identified process are:

a. Implement the plan
b. Check the plan / Check the results
c. Collect the data
d. Analyse the data

Based on the lists above, the “implement the plan” process had also been discovered to have happened in week two of the PB Lab course. Generally, the continuous process in implementing the solution needs longer time for students to connect the circuits, run the programs using the engineering software and most importantly to carefully understand the function of each device or engineering component, so that the results obtained are correct. Apart from that, another related process is “check the plan”. This process is under the “Engineering Design Implementation”. Normally, almost all the students that go through the PB Lab course have to “redo” or trouble shoot their experiments or engineering design because the results obtained are different from those they learned in the theories. Another two process in week three are “collect the data” and “analyse the data”, which are categorised under the Project Analysis criteria. These two process are both related to the data obtained after the completion of engineering designs.

In Week Four, which is the “Solution evaluation” phase, only one main process were discovered by the researcher which is “present the results” Specifically, in these process, the PB Lab facilitators actively participated in listening to the students’ presentation regarding the solution of problems they had adopted. The facilitators also used this final session of the PB Lab course as a time to evaluate the students by asking about the details of solution that they had implemented, the theories or concept behind the problems, and the knowledge gained after the students had successfully solved the problems. Normally, this is the critical week for each student because he or she has to be fully prepared and thoroughly understand the problem.

The above discussions clearly explain why the identified sub-themes (reported in Table 4.3) are also relevant to be consider to be included in the Problem solving Process Rubric (PPR) design. Specifically, after analysing the observation and interview data in Phase I, the researcher notices the triggering factors that lead to the students' achievement of the objectives of the five main problem solving processes (themes) in each of the PB Lab weeks.

However, the effectiveness of all the above process (themes and sub-themes) would not have been achieved if there were less or no communication and teamwork skills. It can be seen, based on the Phase I data that most of the students did the discussions with their team members and with the PB Lab facilitators. This phenomenon happened almost every week in the PB Lab course. Besides, the constructivism theory, proposed by Piaget (1954) and then reviewed by Vygotsky (1978), also states interacting and sharing the knowledge with others and the surrounding people help the students to construct knowledge more effectively. Due to that, the communication and team-working also been selected as an important criteria identified from Phase I.

Table 5.1: The Main and Sub-criteria Identified from Phase I results

Week	**Main criteria for PPR (Themes)**	**Sub-criteria for PPR (Sub-themes)**
Week One	Problem Identification	• Understand the Problem/ Problem statement and problem objectives identification • Information Searching • Application of Knowledge
Week Two	Project Planning	• Plan the Solution / Procedures, Code and Measured Variable Planning Phase • Devices /Component Recognition • Information Searching • Application of Knowledge • Implement the Plan
Week Three	Implementing Engineering	• Implement the Plan / Implementing the Experiment or Design

	Design Project Analysis	• Check the Plan • Collect the Data • Analyse the Data
Week	**Main criteria for PPR (Themes)**	**Sub-criteria for PPR (Sub-themes)**
Week Four	Evaluate the Solution	• Present the Results

5.3.2 Semi-structured Interview II (Data set 3)

Face-to-face interview II is another batch of Phase II data which has been gathered by the researcher. The objectives of this data collection are to identify the PB Lab facilitators' comments and opinions of the previous rubrics for the Project-based Laboratory (PB Lab) course. There are five rubrics used by all of these facilitators in assessing students in the PB Lab course. However, as stated in the problem statement in Section 3.2, these rubrics do not truly assess the outcomes needed by the faculty because of their misalignment issues. The interview sessions conducted by the researcher serve to gain insights into the facilitators' feedback specifically in terms of previous rubrics' criteria, descriptors and level of performance. Besides, they act as a guide to help the researcher avoid making the same mistakes that happened in previous rubrics' designs. In order to answer the question regarding the previous PB Lab rubric's criteria, six experienced PB Lab facilitators from different electrical engineering fields were interviewed by the researcher. All of the interview sessions were conducted in November, 2013. Furthermore, the interview transcription have been analysed using the Thematic Analysis technique. Table 5.2 shows the details of the PB Lab facilitators who participated in the interview sessions.

Table 5.2: The participated PB Lab facilitators

PB Lab Facilitators	PB Lab Conducted	Types of PB Lab	Courses
P8	High Voltage Lab	Hardware based	SKEE
P9	High Voltage Lab	Hardware	SKEE

		based	
P10	Electronic Lab	Hardware based	SKEL
PB Lab Facilitators	**PB Lab Conducted**	**Types of PB Lab**	**Courses**
P11	Telecommunication Lab	Hardware and Software based	SKET
P12	Digital Signal Processing Lab	Software based	SKEL
P13	Digital Signal Processing Lab	Software based	SKEL

The following crucial question had been asked by researcher during the interview sessions to gain insights into the facilitators' feedback in terms of previous PB Lab rubrics' criteria.

"How do you define the clarity of the previous rubrics' criteria?"

The detail of the interview transcription are reported in Table 5.3:

Table 5.3: The results from the Interview II transcripts

PB Lab Facilitators	Description from the Interview II transcript	Codes	Themes
P8	…when the criteria have been set up, it help me a lot. For example, in week one, for the criteria of proficiency, I will observed them preparing samples. If you want to change week one rubrics, you can tried to include it.	- Criteria helped a lot - proficiency criteria- observed students prepared samples.	Misconception of "proficiency using equipment/software" criteria in rubric.
P9	For the criteria of proficiency using equipment/software in week one does't not only means that they already used the Lab view software or not, but for week one, it means that how they used the software such as google or went to the PSZ library to find info.	-Criteria of proficiency in using equipment/software-	
	……in week one, for the criteria of proficiency using equipment/software, they don't use anythings (engineering software), so we have to change the meaning of the criteria itself.	- change the meaning of the criteria itself	
P10	X	X	
P11	….sometimes, some students used hardware and some students used software. That's the	- some used hardware – some used software –	

	problem.	problem. - bullet form – better – less word. - no criteria – thinking and reasoning skills.	Criteria have to many wording.
	I think bullet is more better. Make less wording.		
	…no criteria to measure the thinking and reasoning skills.		
	The critical things is when to apply the theory to the application.		
P12	Agreed with some criteria and not agreed with some criteria.	- Agreed some criteria – not agreed some criteria. - Proficiency criteria in week one – asked the students to write simple coding – if right – proficient.	Misaligment between the criteria and course outcome.
	For the proficiency criteria in week one, I will not gave them 4 because they don't do anything yet. I asked them have they used the Matlab software. If they have used it, I will asked them to write simple coding . If the coding was right, it means that they proficient. I will noticed which students did the coding.		
P13	X	X	

Note: X means not relevant to the RO

Table 5.3 show the details of responses from the PB Lab facilitators regarding the criteria of the previous PB Lab rubrics. Examples of these PB Lab rubrics are contained in the Appendix F for reference. In order to obtain more responses from each of the facilitators, the researcher interviewed them individually at their respective offices. It is important to note that all of these facilitators were aware about the intention of these interview sessions because a notification email was sent to them one week before the interview sessions. As shown, it can be seen clearly that most of the facilitators (P8, P9, P11 and P12) mentioned the criterion of "Proficiency in using hardware/software tools" stated in the rubrics for PB Lab Week One. It has been identified that this criterion is not suitable to be assessed during the PB Lab session in Week One. This is because normally, in the first week of the PB Lab course, most of the students have just obtained their problems to be solved; and usually they will search for more information and identify the problems before proceeding to decide on the hardware or software in Week Two. There is another point stressed by P11 regarding the "hardware and software tool" used by students. The observation done by the researcher in Phase I shows that there are three types of PB Lab laboratories: hardware-based, software-based, and hardware and software-based. All of these laboratories are different from one another because each is based on the Electrical Engineering field itself. According to P11, this is an “issue” or “problem” in creating a PB Lab rubric which covers various types of PB Lab laboratories.

To summarise, there are four important themes mentioned by facilitators that shows facilitators’ feedback in terms of previous PB Lab rubrics’ criteria. These themes were identified based on the issues related to the previous PB Lab rubric to become a guideline to the researcher and avoid doing the same mistakes. The following were the identified issues (themes) :

a. Misconception of “proficiency using equipment/software” criteria in rubric.
b. The criteria have to many wording.
c. Misaligment between the criteria and course outcomes.

5.3.3 Documents (Data set 4)

Documents are another important source of data used by the researcher in developing the Problem solving Process Rubric (PPR) in Phase II. They provide more ideas, information and guidelines for the researcher in determining suitable and valid criteria to be included in the PPR’s design. Besides, the documents support other data collection results in Phase II, such as observation field notes from Phase I and interview II transcripts. There are four types of documents refered to by the researcher in developing the PPR’s criteria. These documents are from the following sources:

a. EAC Engineering Programme Accreditation Manual 2012
b. PB Lab Rubrics (semester 2013/2014)
c. PB Lab Course Outcomes
d. Existing Problem solving Rubrics (15 sets)

All of these documents were analysed systematically using the thematic and document analysis in order to get the meaning of the data so that they can be used in designing PPR. Firstly, in analysing the documents, the relevant description in the documents were coded and the themes was identified. Then, in order to help researcher in analysing the themes across the document, checklist have been used. The details about the checklist are reported in Section 3.7.2.1.

5.3.3.1 EAC Engineering Programme Accreditation Manual 2012

The first document referred to by the researcher is the EAC Engineering Programme Accreditation Manual 2012, which reports details of the requirements set by this accreditation board for all engineering programmes. In developing the PPR design in Phase II, this EAC Manual gives some guidelines to the researcher so that the selected criteria for the PPR design are aligned with the EAC requirements. As known, the objectives of the PPR development are to assess students' problem solving skills. The programme outcomes listed in the EAC Engineering Programme Accreditation Manual 2012 specifically mention the criteria of problem- solving skills needed to be acquired by students. The related EAC programme outcomes state that students must able to perform the following tasks:

Table 5.4: The Analysis of Engineering Manual 2012 (Problem solving criteria)

PO	EAC Program Outcomes	Codes	Themes
PO1	Apply knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems.	Apply knowledge- solve engineering problem	Application of Knowledge
PO2	Identify, formulate, research literature and analyse complex engineering problems reaching substantiated conclusion using first principles of mathematic, natural sciences and engineering sciences.	Identify, formulate, research literature and analyse - engineering problems	Identification of the Problem

PO	EAC Program Outcomes	Codes	Themes
PO3	Design solutions for complex engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.	Design solutions – engineering problem	Implement the plan

The above three programme outcomes (PO)- PO1, PO2 and PO3 show the need for problem solving skills to be acquired by students. Besides that, it is noticed that there are EAC programme outcomes which are also relevant to the context of laboratory work that deals with engineering software and hardware tools. The relevant PO is:

Table 5.5: The Analysis of Engineering Manual 2012 (Laboratory criteria)

PO	EAC Program Outcomes	Codes	Themes
PO5	Create, select and apply appropriate techniques, resourches, and modern engineering and IT tools, including prediction and modelling, to complex engineering activities, which an understanding of the limitations.	Create-select-apply technique – engineering tools – solve engineering problem	Application of Engineering Tools

The programme outcomes related to communication and teamwork skills have also been highlighted by the researcher in this phase. Communication and teamwork skills are necessary to ensure the effectiveness of the problem solving process. These two elements have already been stressed by the researcher in Section 5.3.1; it is observed that communication and teamwork elements are one of the important criteria that help students to go through the PB Lab processes in order to solve problems. In addition, these elements are also listed among the important skills required by EAC such as in PO9 and PO10; students must demonstrate capabilities to perform the following tasks:

Table 5.6 The Analysis of Engineering Manual 2012 (Communication and Teamwork criteria)

PO	EAC Program Outcomes	Codes	Themes
PO9	Communicate effectively on complex engineering activities, with the engineering community and with society with large, such as being able to comprehend and write effective reports and design documentation, effectiveness presentation and give and receive clear instruction.	Communicate-solve complex problem	Communication
PO10	Function effectively as an individual, and as a member or leader in diverse teams and in multi-diciplinary setting.	Function as ateam	Teamworking

These documents highlight several POs that are related to the designing of the PPR's criteria. Six out of twelve programme outcomes selected by the researcher are viewed as guidelines; this is to ensure the criteria listed in the PPR are the outcomes that fulfil the needs of the industries. The following list shows the themes obtained based on EAC POs, which have been refered in designing the PPR's criteria.

a. Application of Knowledge.
b. Identification of the Problem.
c. Implement the Plan.
d. Application of Engineering Tools
e. Communication
f. Teamwork

5.3.3.2 PB Lab Course Outcomes

The second document refered by the researcher is the lists of the PB Lab course outcomes (CO). There are five COs stated by the faculty and all of them have been refered to by the researcher while designing the PPR's criteria. Lists of the COs are found in Chapter 3.

5.3.3.3 PB Lab Rubric

Rubrics have been selected by the PB Lab Task Force members as the PB Lab assessment tools since the year 2005. Starting from the 2005 until 2014, much work had been done in reviewing these rubrics so that they are aligned with the outcomes needed. However, as mentioned in chapter three, the criteria of these rubrics do not truly represent the assessments of problem solving skills although the course outcomes have listed them as the first outcomes needed. Besides, the pedagogy of the teaching and learning of PB Lab course also presents the processes of problem solving that happened. The objective of the researcher in reviewing these PB Lab rubrics from semester 2013/2014 is only to obtain a guideline in terms of appropriate wordings and engineering terminology used so that they are suitable to be included in the PPR design. The examples of these PB Lab rubrics are contained in the Appendix F. Specifically, each rubrics have been collected and reviewed. If the content of the rubrics was relevant to the problem solving, thematic analysis will be used in order to interpret and code the content into potential themes.

Five types of rubrics were used during the semester 2013/2014; however, only one rubric which is the Individual In-Lab Activities Rubric has been referred to in this study due to the relevancy of the terms used in relation to the objectives of the PPR. In terms of the criteria listed in the Individual In-Lab Activities Rubric, only one criterion which is "Proficiency in Using Lab Equipment and/or Software" has been referred to. Other criteria do not match the PPR objectives. Besides, there is also an Individual In-Lab Activities Rubric (Interview Session) which only was used after the students presented their work in Week 4. In assessing the students using this rubric, PB Lab facilitators are required to interview the students individually. This is because the criteria listed in the rubric include questions that must be answered by the students. There are three criteria listed in this rubric: (a) Gist of the problem (What is the problem that you need to solve?); (b) Questions related to required theory or literatures; and (c) Technical questions related to experiments/procedures/hands on etc. As mentioned above, only the criteria "Proficiency in Using Lab Equipment and/or Software" in Individual In-Lab Activities Rubric has been referred to by the researcher.

5.3.3.4 Existing Problem Solving Rubrics

The final document which has been referred to by the researcher is 15 sets of existing problem solving rubrics from various universities and various backgrounds. Generally, up to 1,000,000,000 rubrics have been uploaded by people to the internet and they can easily be found through search engines (Arter and McTinge, 2001). It is important to highlight that each rubric has its own objectives which are suitable for certain context of course or programme. The main reason for the researcher to review these rubrics is to gain insights into dominant problem solving criteria that have been assessed by other researchers or educators; these criteria can then be used as a guideline in designing the Problem Solving Process Rubric (PPR). Besides, the terms and words used in each of these problem solving rubrics also help the researcher to properly select the words used in the PPR so that this PPR's construct can be understood and implemented by other studies.

Table 5.8 and Table 5.9 present the analysis of the 15 sets of problem solving rubrics' criteria which have been referred by the researcher. Specifically, each of the rubric been analysed by determining the rubric's criteria that relevant to the problem solving process. Based on Table 5.1, a complete table of checklist; Table 5.7 have been developed. The purpose of this table is to check across the rubrics any criteria relevant to problem solving. To guide the researcher, the themes and sub-themes occurred in Table 5.1 were referred. The criteria listed in the table 5.7 and 5.8 represent the criteria identified in the 15 sets problem solving rubric from various instituition.

Table 5.7: The Analysis of Existing Problem Solving Rubrics (Problem solving criteria)

Researcher/ Universities	Problem solving Criteria									
	Problem Identification			**Project Planning**		**Implenting Engineering Design**		**Project Analysis**		**Solution Evaluation**
	Understand / Identify problem	**Applying previous knowledge**	**Search/ Collect Information**	**Plan the solution**	**Equipment/ Tools recognition**	**Implement the solution**	**Check the plan**	**Collect the data**	**Analyze the data**	**Present/ Evaluate the solution**
(University of Pittsburgh, 2010)	√	0	√	X	X	0	X	X	√	√
(AACU, 2010)	√	0	0	X	X	√	X	X	√	√
(Saint Paul College, 2012)	√	0	√	X	X	√	X	X	0	0
(Project, 2002)	√	√	√	X	X	√	X	X	√	0
(Merion Technical College, 2005)	√	0	√	X	X		X	X	0	√
(We-Impact, 2011)	√	0	0	X	X		X	X	0	0
(Shreyer Institute for Teaching Excellent, 2007)	√	√	0	X	X		X	X	0	0
(Addendum, 1995)	√	0	0	X	X	√	X	X	√	0

(Deakin Univercity, 2013)	√	0	0	X	X	√	X	X	√	√
(University of Guelph, 2012)	√	0	0	X	X	√	X	X	0	0
(Petrolium, 2000)	√	0	√	X	X	0	X	X	0	0
(Egodawatte, 2010)	√	0	0	X	X	√	X	X	0	0
(Berry, 2013)	√	0	0	X	X	0	X	X	0	0
(Docktor and Heller, 2009)	√	√	0	X	X	0	X	X	√	√
(Alfrey and Cooney, 2009)	√	√	0	X	X	0	X	X	√	√
	15	**4**	**4**	**X**	X	0	**X**	**X**	**6**	**6**

Note: X means not included in the existing rubric.

Table 5.8: The Analysis of Existing Problem Solving Rubrics (Communication and Team working)

Researcher/ Universities	**Communication**	**Team working**
(University of Pittsburgh, 2010)	0	√
(AACU, 2010)	0	0
(Saint Paul College, 2012)	0	0
(Project, 2002)	0	√
(Merion Technical College, 2005)	0	0
(We-Impact, 2011)	√	√
(Schreyer Institute for Teaching Excellent, 2007)	0	0
(Addendum ,1995)	0	0
(Deakin Univercity, 2013)	0	0
(University of Guelph, 2012)	0	0
(Petrolium, 2000)	0	0
(Egodawatte,2010)	√	0
(Berry, 2013)	0	0
(Docktor and Heller, 2009)	0	0
(Alfrey and Cooney, 2009)	0	0
	2	**3**

Table 5.7 and Table 5.8 show the details of analyses which have been done to identify the dominant and the most frequently selected criteria used by other researchers or universities. It can be seen clearly that Table 5.7 represents the total number of problem solving criteria which have always been highlighted by educators, and some of them are as follows: (a) define/restate a problem; (b) develop a plan; (c) search information; (d) analyse and interpret data; and lastly (e) present or evaluate a solution. There are several other problem solving rubrics which have included the elements of communication and teamwork as two of their rubrics' criteria. It can be seen the results in Table 5.8 represent five out of fifteen rubrics that assessed these elements whereas others totally focused on assessing elements of

problem solving skills. To review more, refer to these rubrics included in the Appendix G.

5.3.4 Results

To summarise, in developing the Problem solving Process Rubric's (PPR) criteria in this study, three sets of data have been collected and the relevant criteria have been determined in each of these sets of data to be included in the first version of PPR's design. To ensure all the selected criteria from each set of data are matched and triangulated with each other, the triangulation process was done by the researcher. This process requires the researcher to analyse, review and summarise each of the data sets until the final results of PPR's criteria are obtained. Besides that, by conducting the interview session II with the six PB Lab facilitators, the researcher could highlight the weaknesses that occurred in the previous PB Lab rubrics and try to avoid them in the present PPR design. Table 5.9 and Table 5.10 represent the criteria which were triangulated from all the data sets.

Table 5.9: The Results of Problem solving Criteria

Data set / Sources		Problem Solving Criteria									
		Problem Identification			Project Planning		Implenting Engineering Design		Project Analysis		Solution Evaluation
		Understand / Identify problem	Applying previous knowledge	Search/ Collect Information	Plan the solution	Equipment/ Tools recognition	Implement the solution	Check the plan	Collect the data	Analyze the data	Present/ Evaluate the solution
Phase I Observation Data		√	√	√	√	√	√	√	√	√	√
Documents	EAC Engineering Programmes Accreditation 2012	√	√	0	√	√	√	0	0	√	0
	PB Lab course outcomes	√	√	√	√	√	√	0	0	√	0
	Previous PB Lab rubrics (semester 2014/2015)	0	0	0	0	√	0	0	0	0	
	Existing Problem solving Rubrics	√	√	√	0	0	√	0	0	√	√

Table 5.10: The Results of Communication and Teamworking Criteria

Data sets/ Source		**Communication**	**Teamworking**
Phase I Observation Data		√	√
Documents	EAC Engineering Programmes Accreditation 2012	√	√
	PB Lab course outcomes	√	√
	Previous PB Lab rubrics (semester 2014/2015)	√	0
	Existing Problem solving Rubrics	√	√

Table 5.9 and Table 5.10 illustrated the triangulation process that matches all the criteria analysed in each data set and compares them with those from other data sets. This is done in order to show the criteria that overlap with each other. Besides that, by triangulating the criteria obtained from the Phase I and several existing problem solving rubrics with the EAC and PB Lab outcomes, a strong alignment is seen to have occurred between the data; in this manner, the criteria to be assessed are aligned with the learning outcomes needed.

Due to that, the researcher have selected the criteria listed in Table 5.9 and Table 5.10 as the criteria for the Problem solving Process Rubrics (PPR). However, throughtout the analysing process, several criteria have been found by researcher many times when reviewing the problem solving rubric from other instituition. The criteria were; (a)Interpretation of Information; (b) Proficiency using hardware and/or software; (c) Troubleshooting the problem and (d) Interpretation of results. These criteria are dominant and mostly been assessed in problem solving rubric. Due to that, these criteria also been added in PPR.

Table 5.11 shows the details of the selected main criteria and sub-criteria to be included in the first version PPR design; they are divided and spread over the four weeks of PB Lab course. It can be seen that there are some criteria been assessed in several weeks. This is due to the continuous process of problem solving happened in each PB Lab weeks.

Table 5.11: The selected main and sub-criteria for PPR's design

Week	Main Criteria	Sub-criteria
Week 1	Problem Identification	• Defining the problem • Applying basic knowledge • Information searching • Interpretation of information • Communication and Fulfilment of task
Week 2	Plan the Solution	• Developing the plan • Applying basic knowledge • Information searching • Interpretation of information • Hardware/ software recognition • Proficiency in using equipment and/or software • Troubleshooting the problem • Communication and fulfilment of task
Week 3	Implement the Solution	• Hardware/ Software recognition • Proficiency in using equipment and/or software • Troubleshooting the problem • Interpretation of information • Applying basic knowledge
	Check the Plan	• Interpretation of results • Communication and fulfilment of task
Week 4	Evaluate the Solution	• Evaluate the solution • Applying basic knowledge • Interpretation of results • Communication and fulfilment of task

5.4 Descriptors for Problem Solving Process Rubric (PPR)

The next step of completing the design of the Problem Solving Process Rubrics (PPR) is developing the descriptors under each level of each criterion. Generally, based on literature review, there is a researcher who implemented the levels of performances as the second step after choosing the rubric's criteria. But, in this study, by referring to the step-by-step of rubrics' development processes proposed by Mertler (2001), the developments of the descriptors have been focused on after the criteria's development. As known, descriptors are the details of the students' performance quality (Brookhart ,2013). There are several common ways to write the descriptors which have been discussed by several researchers such as (Glatthorn, 1999) and Brookhart (2013). Some researchers recommend beginning by specifying two extreme descriptors which are "best" and "worst" (Glatthorn, 1999). It is quite easy to differentiate between these two extreme levels due to the clear indicators of the two descriptors. Besides that, another common way used in developing descriptors is by writing the description for the top categories first (Brookhart, 2013). To help and guide the researcher in writing good descriptions, the following question proposed by Brookhart (2013) is used.

"What does students' work look like at this level, on this criterion?"

In this section, three data groups (Data set 1, Data set 3 and Data set 5) are used to select the descriptors for the PPR design. Importantly, the construct of the descriptors in this section is done by dividing the performances into three basic levels: "Excellent" indicates top-performance; "Good" indicates medium-performance and "Poor" indicates down or worth-performance. The usage of this range of three basic levels helps the researcher to clearly differentiate them. The details of the analysis are discussed below.

5.4.1 Phase I Results

The Phase I results have been refered by researcher in order to define the students' reaction in the PB Lab course (observation) and the facilitators' opinion (interview I) while facilitating students. It can be observed that there are differences between students' reactions in the laboratory; they can be used to describe the descriptors for each criterion under each level of PPR design. Furthermore, the facilitators' respond in interview II also reported the details on how they assess the students. The following Table 5.12 shows the identified observable students' action in detail.

Table 5.12: The Phase I data

Phase I Sub-themes	**Students' Action (Description from Phase I Observation data)**	**Criteria can be assessed (Determined descriptors)**
Applying Basic Knowledge	-…students tried to answered but cannot answered it correctly. -..students A, B and C seems tried to answer the question but the rest just look at them. - not all students involved in answering the questions.Only two students seem tried to draw the graph although they not really sure about it.	-Correctness of the answer given. -Can apply the previous knowledge accurately. -Contribution in answering the questions.
Search information Share information	-…students sat in a group and reading some references that they bought. - Three students bought laptops and others reading and writing something on paper. Most of them reading journal in the laptops. -..one student keep reading one references book that she bought….while others don't do anything. Just look at what's their friend doing. - Two student meet the technician and asked about the trainer. -One student gave her ideas about the connection and explain it to other student. -Some students found many information, but some students just listen to others ideas. -..some student can explain whats info that she got but others just repeat what her friend said.	- What are the references? - Numbers of the information obtained. -Relevency of the information obtained. -Interpretation of the information and used of it for the problem. -Contribution in group works.
Plan the solution Proficiency in using equipment and/or software.	-..draw circuit on the paper and tried to match it with circuit on the trainer. - ..two students went to other lab to get some components while others started designing the circuit. - …draw the circuit and discussed… - …went to next room to find component. Start discuss the function of each component. - …put component on the board. - ..stand up and look at the devices that they will used.	-Ability to identify correct tools to use and know the function. -Ability to plan the connection. -Ability to explain about the connection implemented. - Contribution in group works

Hardware/ software recognition	- ..look at what types of tranformers to use. - Three students went to the trainer and tried to understand how it's function. - One students put the wires on the board while another one student connect it.	
Trouble shoot	- ..one students adjust the circuit and others just look at her action. - ..one male students adjusted the circuit because the results obtained were not right. - One students keep re-do the circuit until the circuit complete and got the exact results.	-Ability to plan the connection. -Ability to explain about the connection implemented. -Ability to identify and solve the problem occurred. - Contribution in group works
Collect data Interprete the data	- One students took a picture of circuit connection. - One student want to complete the table first before proceed to the connection. - One student took the output of the data and others helped her. - One student show the PB Lab facilitator their simulation results and explained it.	-Ability to determine the relevant results needs. -Ability to describe the results obtained. -Ability to explain about the results. -Contribution in group works

Table 5.12 presents the details of the description taken from the observation field notes and interview I transcription that show the students' reactions while going through the problem solving process in the PB Lab course and the facilitators' respond. The thorough analysis done by researcher has successfully listed the details criteria, which can be used as a guideline in developing the PPR's descriptors. These observation data help the researcher determine and describe the students' observable reactions. The actions observed indicate several elements which can be assessed and included as descriptors under the criteria in the PPR's design.

5.4.2 Face-to-face Interview II (Data set 3)

The second data set used in selecting the descriptors of the PPR's design is the face-to-face interviews. As discussed earlier, Section 5.3.2 shows the details of the six PB Lab facilitators interviewed; the purpose of the interviews is to obtain their feedback regarding the previous PB Lab rubrics. The following Tables 5.13 shows the results of interview data.

Table 5.13: The results from the Interview II transripts

PB Lab Facilitators	Description from the Interview II transcript	Codes	Theme
P8	…conformtable with the wording..	Wording	The long wording.
P9	The rubrics is not clear It's not quantify. More towards the individual assessments	Not clear. Not in the quantitative	
P10	**….**the wording is too long. ….it asked to assess the profiency in week one, although in week one, there just only brainstorm.	Word- too long. Proficiency in week one.	
P11	**X**	**X**	**X**
P12	**X**	**X**	**X**
P13	**X**	**X**	**X**

Note: X means not relevant to the RO

Based on Table 5.15, it is clearly shows that only three out of six PB Lab facilitators responded and gave comments about the description of the rubrics. Two facilitators (P8 and P10) mentioned that the wording of the descriptors was too long. Besides, it can be determined that most facilitators commented about the clarity of the descriptors; they are too wordy and subjective and hence difficult to be assessed. Here, the researcher lists two important points (themes) obtained from the interview sessions, which can be a guideline in developing the PPR's descriptors:

a. The wording.

5.4.3 Documents (Data set 4)

Only two types of documents referred by the researcher were used as guidelines in developing the Problem Solving Process Rubric's (PPR) descriptors. They are the previous PB Lab rubrics (semester 2014/2015) and the existing problem solving rubrics obtained by the researcher. The following section discusses in detail the documents used.

5.4.3.1 PB Lab Rubrics (Semester 2013/2014)

In developing the descriptors for the PPR design, it is important to understand each of the criteria listed. An overview of the best performances was obtained, which can be used as a guide to describe the PPR's descriptors. The descriptors listed in the previous PB Lab rubrics (Semester 2013/2014) under the "Proficiency in using equipment and/or software" criteria were referred to by the researcher as references. There are four levels of descriptors under these criteria; examples are as shown in Table 5.14:

Table 5.14: The example of previous PB Lab rubrics' descriptors

Criteria	Level of Performances			
	Excellent 4	Good 3	Fair 2	Poor 1
Proficiency in using equipment and/or software	Able to sets up equipment and collects data in an efficient manner. **Fully utilise** the software tools to analyse and display the data collected.	Able to sets up equipment and collects data in an efficient manner. **But not, fully utilise** the software tools to analyse and display the data collected.	Able to sets up equipment and collects data in **less efficient manner.** **Not fully** utilise the software tools to analyse and display the data collected.	**Not able** to set up equipment and utilize the software tools.

The example of the previous PB Lab rubrics above presents the descriptors under the "Proficiency in using equipment and/or software" criterion, which focuses on assessing student's ability to set up equipment, collect data and utilise software tools. Clearly, in describing each of these descriptors, this rubric uses words such as "Fully utilise", "Not fully utilise", "Less efficient" and "Not able". These words are more appropriate for "subjective" descriptors which cannot quantify performance with rates. For example, how to identify whether data have been collected in an efficient manner or in a less efficient manner? How to define less? It is advisable to have one or more words that can quantify performance with rates; this will help facilitators to differentiate the various levels of a student's potential. Therefore, it is significant that the words used in designing rubrics should be properly chosen so that they can effectively help facilitators to assess students' performance, especially through observations.

5.4.3.2 Existing Problem Solving Rubrics

15 sets of existing problem solving rubrics were collected and thoroughly analysed by the researcher; the results of the analysis were used as a guide in determining the common descriptors which had been assessed by other educators. Table 5.15 presents the frequently assessed descriptors in detail.

Table 5.15: The Analysis of Existing Problem Solving Rubrics (Description)

University/ Researcher	Problem Solving Descriptors									
	Problem Identification			Project Planning		Implementing Enginnering Design		Project Analysis		Solution Evaluation
	Understand problem/ Identify problem	**Apply knowledge**	**Search /Collect information**	**Plan the solution**	**Equipment/ Tools recognition**	**Implement the Solution**	**Check the plan**	**Collect the Data**	**Analye the Data**	**Present /Evaluate the Solution**
(University of Pittsburgh, 2010)	Identified objectives of the problem.	0	Relevancy of the information obtained with problem given.	X	X	0	X	X	Appropriateness of the analysis. Reasonableness of the solution.	Able to explain the solution fluently.
(AACU, 2010)	Clear problem statement.	0	0	X	X	Identify multiple approach of solutions.	X	X	The details analysis.	Thoroughly review the results.
(Saint Paul College,2012)	Identify problem statement.	0	-Number and sources of the information. -The interpretation of the info.	X	X	-Identify the solution. -Explain reasoning.	X	X	0	-Demostrated the processes. -Thoroughly explain the results
(Project, 2002)	Clearly defines problem's	-Apply knowledge with	-Number of information obtained.	X	X	-Identify plan and necessary steps taken.	X	X	-Concisely explain the results.	-Draw correct conclusion.

	objectives.	current problem. -Share the knowledge with others.	-Intergration of information with problem.						-Relates the results with the theory.	
(Merion Technical College, 2005)	-Identify the problem.	0	-Relevancy of the information. -Number of information obtained. -Able to isolate the variables relates with problem.	X	X	-Identify multiple solution. -Determine the plan strength and weaknesses.	X	X	0	-Convincingly evaluate the solution.
(We-Impact,2011)	-Clearly identify the problem and issues.	0	0	X	X		X	X	-Draw the conclusion from the results.	-Convincingly evaluate the solution.
(Schreyer Institute for Teaching Excellent, 2007)	-Outline the problem objectives. -Assistances.		0	X	X	-Develop logic strategies. -Assistances.	X	X	0	0
(Addendum, 1995)	Determine the problem's issues.	Select and implement relevant concept.	0	X	X	Implement relevant procedures.	X	X	0	0

(Deakin Univercity, 2013)	Restate the problem	0	0	X	X	Develop clear strategy.	X	X	0	Reasonableness of the results.
(University of Guelph, 2012)	Restate the problem.	0	0	X	X	Acted on plan.	X	X	Tested the outcomes and reflected the results.	Tested the outcomes and reflected the results.
(Petrolium, 2000)	Identify problem's issues.	0	0	X	X	Create plan.	X	X	0	0
(Egodawatte, 2010)	Identify the problem's objectives.	0	Relevancy of the information.	X	X	0	X	X	0	0
(Berry, 2013)	Understanding of the problem.	0	0	X	X	Plan reasonable plan.	X	X	0	0
(Alfrey and Cooney 2009)	Define problem	0	0	X	X	Proposed multiple soluton	X	X	Conclusion and Evaluation	Apply method to generate result

Table 5.17 shows the details of descriptors which have been assessed by most researchers under the problem solving criteria. Several descriptors categorised under the criteria (based on Table 5.1) have been analysed and it can be seen that some of them focus on the same output. For example, most of the descriptors under the "Understand/ Identify Problem" criterion focus more on assessing the correctness and clarity of a problem's statement, objectives and issues. Only one descriptor highlights the "assistances" element under this criterion. This element is one of the observable descriptors that can help facilitators to assess students' performance through observation during the learning activities. Under the "applying the knowledge" criterion, the trend of the descriptors is focusing more on correctness and application of knowledge in solving problems. It is important to highlight that the descriptors under the "Search information" criterion focus more on the numbers of the information sources obtained by students. The "analysis of results" and "solution evaluation" criteria, stress mostly on the appropriateness and the reasonableness of the solutions obtained. Details of the selected descriptors which have been constructed by the researcher and to be included in the PPR design are discussed as below.

5.4.4 Results

To summarise, three main groups of data were gathered in helping and guiding the researcher to develop the descriptors of Problem Solving Process Rubric (PPR); most of them clearly show the descriptions which can be written under each criterion. Before writing the description of the PPR descriptor, the researcher divided the levels of the descriptors to be designed in three basic scales: "Excellent" indicates top-performance; "Good" indicates medium-performance; and "Poor" indicates down/worth-performance. By using this range of basic levels, the researcher has a clear mind to construct and write the descriptions which represent top, middle and down performances systematically. The results obtained from the Phase I observation data present several observable reactions of students, which help the researcher to describe the criteria. For example, it can be seen that some students performed well during the PB Lab activities by actively engaging with team members and they took part in solving the problems. However, there were also some students who sat around passively, and they contributed less in terms of group work. In addition, data obtained from the public documents such as previous PB Lab rubrics and sets of existing problem solving rubrics, have guided the researcher in selecting and constructing the descriptors that had been commonly assessed under the problem solving process criteria. The researcher also evaluated the PB Lab facilitators' feedback on the previous PB Lab rubric's descriptors, in order to highlight any strengths and weaknesses of the rubrics so that they can be used as a reference point in developing the descriptors for PPR. It is important to highlight that the selection of action verbs used in the PPR's descriptors has been made with reference to the Bloom's Taxonomy action verbs (Appendix L), so that each of the verbs used represents the level of a student's cognitive domain.

After all the data have been reviewed, the researcher describes six levels of performances. The first version of descriptors designed by the researcher can be viewed in the first version of PPR's design contained in the Appendix H.

5.5 Level of Performance for Problem Solving Process Rubric (PPR)

The levels of performances are another part of the rubric's design, which can categorise and differentiate the students according to their quality of performance. Zimmaro (2007) discusses two types of rubrics' levels which are commonly used nowadays: levels based on "numbering scales" (e.g. scale 1-3); and levels based on "quality" (e.g. Less good, good, excellent). Until now, there is no fixed formula for determining rubrics' scale (Stevens and Levi, 2005). However, based on the literature, a scale is normally in a range between three to six (Glatthorn, 2013).

In this section, the final rubric's construct which is development of the levels of students' performance in the Problem Solving Process Rubric (PPR) is discussed. The researcher focuses on this step after completing the criteria and descriptors of the PPR's design. As mentioned in Section 5.4, the description of this PPR's design was done by dividing the performances into three levels so as to differentiate the quality of students, which are Excellent, Good and Poor. By using this range of basic levels, the researcher can clearly determine the top, middle and down categories systematically. But, it must be emphasised that, the three levels described are not the final levels of performances of this PPR design. There are other additional levels of performances which have been constructed by the researcher after thoroughly reviewing and analysing the collected data sets.

5.5.1 Face-to-face Interview II (Data set 3)

Face-to-face interview II transcripts are one of the data sets used in constructing the levels of performances for the PPR design. This data set has been analysed and used in designing all the PPR parts such as criteria, descriptors and levels. The results of this process present valuable comments and feedback from the PB Lab facilitators who have conducted this PB Lab course for several years. The results obtained are presented in Table 5.16.

Table 5.16: The results from the Interview II transripts (Distinction of Levels)

PB Lab Facilitators	Description from the Interview II transcript	Codes
P8	…if the rating criteria can be add more, it is more better. ..sometimes..for examples the report content is fuzzy, so I'm also fuzzy but level 4 is much ok..	Add more rating scales.
P9	Sometimes, I felt in between. I will gave half marks for students..i like to give range between 3 to 4. Don't fixed the point.	Give middle marks for students. Don't fixed the scale number.
P10	**X**	**X**
P11	Not so difficults..but if I want to give them 4 for excellent is too high for them.	Scale 4 is too high
P12	Although the level given in the 1234, but I still put it in a point. Sometimes I felt he deserve to get more than three, but his not excellent enough.	Give in point form
P13	**X**	**X**

As shown in Table 5.15, clearly reveal that some of facilitator put the marks in point form, and this is not in accordance with the design of the rubric which is in the form of levels. Based on this, the researcher has decided that in order to develop the PPR's levels of performances, attention must be given in terms of "the meaning of the levels itself"; each level must be clearly defined and capable of properly describing the performance of the students.

5.5.2 Documents (Data set 4)

The main document which was analysed and used to guide the researcher in constructing the PPR's levels is the sets of existing problem solving rubrics. All the levels of these rubrics have been reviewed by the researcher in order to obtain the most common scales used by other researchers. It can be noticed that the previous PB Lab rubrics (attached in the Appendix F) implemented 4-scales in assessing the students. The following Table 5.17 shows the dominant scales used by other rubrics' design.

Table 5.17: The Existing Problem Solving Scales

University/ Researcher	**Levels of Performances**		
	3 scales	**4 scales**	**5 scales**
(University of Pittsburgh, 2010)	√		
(AACU,2010)		√	
(Saint Paul College,2012)		√	
(Project, 2002)			√
(Merion Technical College, 2005)		√	
(We-Impact, 2011)		√	
(Schreyer Institute for Teaching Excellent, 2007)			√
(Addendum ,1995)	√		

(Deakin Univercity, 2013)		√	
(University of Guelph, 2012)		√	
(Petrolium, 2000)	√		
(Egodawatte ,2010)			√
(Berry, 2013)	√		
(Docktor and Heller, 2009)			√
(Alfrey and Cooney, 2009)		√	
	4	7	4

Based on Table 5.17, the most common scale used by other universities or researchers is 4-scales. It clearly shows that ten out of twenty existing problem solving rubrics collected choose 4-scales to be implemented in their rubrics. These might be due to the number of the descriptors which describe performances according to courses and target learning outcomes. More importantly, as long as the levels are distinguishable and the difference from one scale to another can be described, the number of scales is not an issue (Brookhart, 2013).

5.5.3 Results

To summarise, the scale selected to be included in the first version of the Problem Solving Process Rubric (PPR) design is 6-scales. The six levels of students' performances are set in the range of 5 (Exemplary) followed by 4 to 3 (Proficient), 2 to 1 (Developing) and 0 (Need Improvement). The selection of the 6-scales was based on its suitability for the descriptors described in the present rubric. The statement mentioned by Bookhart (2013) is relevant: "how many levels of performances in the rubrics" depends on "how many levels that can be described in terms of meaningful differences in performance quality". It is important to ensure that the selected scales are not too few such that facilitators cannot differentiate them, and not too many such that they become more complicated (Lane et al., 2015). As stated by Galtthorn (1999), the common scales usually implemented by others are in a range of 3 to 6 scales.

Besides, as mentioned by PB Lab facilitators in Section 5.5.1, the 4-scales used in the previous PB Lab rubrics is not really clear and the levels are difficult to differentiate. Therefore, in this study, the 6-scales is constructed by the researcher; hopefully it can clearly present differences in terms of the performance qualities on the scales.

Finally, the first construct of Problem solving Process Rubrics (PPR) for version one can be refered in Appendix H.

5.7 Conclusion

This chapter has discussed in detail the development of the Problem Solving Process Rubric (PPR) for this study. There are three parts in the rubric's design which have been highlighted: (a) Rubric's criteria; (b) Rubric's Descriptors; and finally (c) Rubric's Levels of Performances. Data sets gathered and analysed in this study include the following: Phase I observation data, Interview II and Public documents; the data collection and analyses and the construction of the PPR's design have been discussed in detail. All the data sets were compared and triangulated so that they can be matched together and become a construct for the first version of the PPR's design before it can be validated. It is important to highlight that this first version of PPR's design has not been validated yet All the words, terms and levels of the PPR's first version were constructed based on the collected data as discussed above. Chapter 6 will discuss in detail the processes of validating the PPR's design in terms of the experts' perspectives, so that a validated Problem solving Process Rubric (PPR) is able to assess students' problem solving skills in engineering laboratory, especially for the PB Lab course.

Table 5.18: Research Question II and Findings

Research Question	**Findings**
RQ2(a) What are the criteria of the problem solving process which are appropriate to be included in the PPR design?	There are five main criteria include in the PPR design: Problem Identification Project Planning Implementing Engineering Design Project Analysis Solution Evaluation There are ten sub-criteria include in PPR design: a. Defining the problem b. Applying Basic Knowledge c. Information Searching d. Interpretation of Information e. Developing the Plan f. Hardware/Software Recognition g. Proficiency in using equipment and/or software. h. Troubleshooting the problem. i. Interpretation of result j. Evaluate the Solution k. Communication and Fullfillment of task
RQ2(b) How many levels of students' performances that need to be included in the PPR design?	Six levels of students' performances are set for PPR starting from 5 (Exemplary) followed by 4 to 3 (Proficient), 2 to 1 (Developing) and 0 (Need Improvement).
RQ2(c) What are the descriptors of students' performances which are appropriate to be included in the PPR?	Refer to Appendix H.

CHAPTER 6

RESULTS AND ANALYSIS OF PHASE III

6.1 Introduction

Validity is an essential aspect to be focused on when students' performances are being assessed by an instrument. As in this study, a rubric has been chosen as an instrument and assessments tool to measure students' problem solving skills, especially in the PB Lab course. This analytic Problem Solving Process Rubric or also known as PPR has been carefully developed by the researcher in Phase II based on several qualitative data sets. However, a question arises, how to ensure that this design of PPR developed is valid and can truly measure students' outcomes? Thus, this chapter reports in detail how the Problem Solving Process Rubric (PPR) has been validated.

6.2 Phase III: Validation of Problem Solving Process Rubrics (PPR)

As highlighted in Chapter One, the final objective of this study in Phase III is to examine the validity of the PPR's design, including its content and construct. Although the Mertler (2001) step-by-step rubric development process does not include the validity aspect in its models, the researcher took the initiative in validating and testing the PPR's design in the real-world setting so that the PPR's weaknesses and strengths can be determined and revised if necessary. Although only two aspects of validity will be analysed in this study, the process of the rubric which requires validation by the experts is discussed. It is important to mention that in this study, experts' review is chosen as the method to check the PPR's content and construct.

According to Nicholson *et al*., (2009), in validating the performance assessments, experts' review is the first way or method chosen by most researchers to obtain empirical evidences. It may be due to the need of the experts who understand the knowledge or skills that are relevant and be included in the assessments. There are several criteria of the experts listed by Akbari and Yazdanmehr (2014) and Palmer *et al*. (2005), and one of them is regarding the experiences and deliberate practices of the experts. According to Sternberg (1998), in the model of developing expertise, the author stresses that individuals develop their expertise when they actively work in a specific domain. It can be emphasised that, the more a person engages in the practice of the domain, the more skilful he will become. Thus, in this study, three experts have been chosen to validate and review the Problem Solving Process Rubric's (PPR) design. A short biography of each expert is stated in this chapter, followed by the comments and feedback they gave before the PPR design was validated. The specific research questions that guide the discussion of this chapter are as shown in Table 6.1.

Table 6.1: Validity Aspects and Research Questions

Types of Validity	Research Questions (RQ)
Content Validity	Does the PPR measure the required problem solving outcomes it is intended to measure?
Construct Validity	Are all of the important aspects of problem solving outcomes evaluated through the PPR?

6.3 Content Validity

According to Linn (2015), American Psychologist Association lists three types of validity recognised by the Standards for Education and Psychological Tests, and one of them is content validity. Content validity refers to how far an instrument reflects a student's knowledge of the content area (Moskal and Leydens, 2014).Thus, in the context of rubric's design, the validity aspects must be noted because the levels of performances in the rubric itself are indicators for a student's progress and performance. If the content of the rubric fails to assess and does not align with the required learning outcomes, then the rubric's marks obtained by the student will not truly represent the student's performance later. In this study, in order to ensure that the Problem Solving Process Rubric's content is designed to measure the required problem solving outcomes for which it is intended to measure, two experts from the Faculty of Electrical (FKE) were engaged to review and validate the PPR's content in Phase III.

Expert A is an experienced PB Lab facilitator who has conducted the PB Lab course for the SET (Electrical Engineering- Telecommunication) programme since 2007. Besides, she has 25 years of teaching experience in the Faculty of Electrical Engineering (FKE), Universiti Teknologi Malaysia (UTM), and this experience is the foundation and source of her expertise in electrical subject contents. Now, she is the Manager in Academic Audit, Accreditation and Recognition Centre for Quality and Risk Management (QRiM), which is responsible for accreditation and formulation of academic and service policies to meet the needs of the stakeholders and the university. More importantly, she has been selected for this study based on her high achievement, contribution to and expertise in electrical engineering content knowledge, PB Lab courses and the accreditation policy. Judging from her expertise, the researcher has the confidence that she is able to review and validate the content of the Problem Solving Process Rubric (PPR) so that they will align with the outcomes needed and are relevant to the implementation for the PB Lab course.

Another important person for this phase is Expert B, who is an experienced senior lecturer in FKE, with more than 20 years of teaching experience, especially in electrical and electronic subjects. She also has experience as a Coordinator of PB Lab laboratory course from the years 2010 to 2012; this lecturer is responsible for arranging, revising and implementing the PB Lab course's instructional and assessment design. She was selected to be one of the experts in reviewing the PPR's content design because of her experience and commitment in conducting the project-based learning in PB Lab course since 2007. It can be summarised that both of these two experts each have more than 20 years of teaching experience in electrical field and are experts in electrical engineering subject contents. In this Phase III, both of the experts are responsible for reviewing the content of the PPR design, and to check whether it is aligned with the outcomes of problem solving intended in the PB Lab course. The sentences, words and any electrical terms included in the PPR's criteria and descriptors were also reviewed by them, in order to ensure appropriateness and relevance.

The validation process of PPR's content design started after the researcher constructed the first version of the Problem Solving Process Rubric's design in Phase II. This process was conducted in early July, 2014 and ended in September, 2014. It is important to state that this validation process was carried out step-by-step starting with Expert A and then followed by Expert B. The first version of the PPR's design was reviewed by Expert A in three cycles. In order to better understand the process, the researcher has attached various PPR versions in the Appendix H (1st PPR version), Appendix I (2nd PPR version) and finally Appendix K (4th PPR version). Table 6.2 shows the validation details.

Table 6.2: Validation details

No.	Subjects	Details
1.	Experts	A
2.	Types of Validation	Content Validity
3.	No. of validation process	3 cycles
4.	Date of validation	First cycle: 14 July 2014 (First version) Second cycle: 12 August 2014 (Second version) Third cycle: 30 September 2014 (Fourth version)

The details of the reviews and comments from Expert A are reported in Table 6.3 below.

Table 6.3: Expert's A Feedback on First, Second and Fourth PPR version

Rubric's Version	**Problem solving Process Rubric's Correction Details (Comments from Expert A)**
First Version	PPR (Week 1): • Changed the word "correctly" to "clearly". • Be specific on the descriptors of "some mistakes" • Related the assessed descriptors with thinking skills. • Differentiated the descriptors "With little assistance" and "With assistance" • Emphasised the different level of knowledge to the problem. • The importance of "relevant information" as descriptors.
	PPR (Week 2): • Added the "effective" words. • Emphasised the different levels of knowledge to the problem. • The importance of "relevant information" as descriptors
	PPR (Week 3): • Added the "troubleshooting" as one of the descriptors assessed. • Defined "correctness of the results/output obtained". • Emphasised the descriptor of "writing skills" • Differentiated the "Communication and Fullfillment of Task" criteria.
Second Version	PPR (Week 1): • Differentiated between "identify" and "define" verbs. • Changed the "Applying Basic Knowledge" criteria to "Applying Previous Knowledge" criteria. • Defined the "relevant" and "not relevant" words. • Defined more clearly about the "communication and fulfilment of task" criteria. • Scale " 0 " must be changed. Cannot be zero. • Changed the "fulfilment of task" criteria.

	PPR (Week 2): • Changed the "Plan the Solutions" criteria to "Project Planning". • Checked back the "Hardware/Software" terms whether it is suitable to use for the Digital Signal Processing Laboratory or not. • Changed the words "troubleshooting" to "diagnose". • Used the verbs from Bloom's Taxonomy
	PPR (Week 3): • Changed the "Implement the Solution" criteria to "Problem solving Solution". • Changed the "Unable to suggest alternative way" descriptors. • Changed "Check the Solution" criteria to "Project Planning" criteria.
	PPR (Week 4): • Defined the "relevant solution" descriptors.
Fourth Version	• No comments in terms of rubric's criteria, descriptors and levels. • Approved for implementation.

Table 6.3 shows the comments and feedback given by Expert A. During this validation process, Problem solving Process Rubric (PPR) has been revised three times. Generally, based on the comments above, most of the corrections needed during this process are in terms of the following: (a) the verbs used (for example the verb "identify" and "define" ; and (b) the words used (for examples "Basic knowledge" and "Previous knowledge"; "Troubleshooting" and "Diagnose", "Plan the Solutions" and "Project Planning". There are also several criteria that need to be refined in order to ensure suitable description for the assessed criteria. Expert A proposed several descriptors to be included in the PPR's design such as the descriptors regarding the thinking skills and levels of knowledge. After reviewing and analysing all the comments and opinions regarding the Problem solving Process Rubric's criteria and descriptors, the researcher changed the first version of the PPR, and then the second version of PPR's design so that they can include the right criteria and descriptors to be assessed. The researcher referred to Bloom Taxonomy Action Verbs (as attached in Appendix L) in determining the proper and suitable verbs used

to represent the different levels of knowledge. Besides that, there are also comments regarding the PPR's levels of performances used. As seen in the second version of PPR's design (in Appendix I) , Expert A did not agree with the "0" scale. Therefore, the scale of performances for the third version of PPR's design was changed from "0 to 5" scale into "1 to 6" scale. The complete set of PPR second version can be referred to in Appendix I.

After revising the second version of the PPR's design, the third version of PPR's design was developed according to the comments and opinions from Expert A. The third version of PPR's design was reviewed by Expert B. The details of validation by Expert B are presented in Table 6.4 while the details of comments and the review are reported in Table 6.5.

Table 6.4: Validation details

No.	**Subjects**	**Details**
1.	Experts	B
2.	Types of Validation	Content Validity
3.	No. of validation process	2 times (3^{rd} PPR version and 4^{th} PPR version)
4.	Date of validation	23 September 2014 (Third version) 30 September 2014 (Fourth version)

Table 6.5: Expert's Feedbacks on the Third and Fourth PPR versions

Rubric's Version	**Problem solving Process Rubrics' Correction Details (Comments from Expert B)**
Third Version	PPR (Week 1): • No comments
	PPR (Week 2): • No comments
	PPR (Week 3): • Differentiated between "Hardware and/ or Software Recognition" criteria and "Proficiency in Using Equipment and/or Software" criteria. • Added another criterion regarding "Engineering Design" criteria. • Revised the descriptors under the "Proficiency in Using Equipment and/or Software" criteria. • Revised the "Interpretation of results" criteria.
	PPR (Week 4): • Cut the "Applying Previous Knowledge" criterion from Week 4 rubrics.
Fourth Version	• No comments in terms of rubric's criteria, descriptors and levels. • Recommended to revise the rubric's format (in terms of rubric's table). • Approved for implementation.

Table 6.5 presents the feedback given by Expert B. It can be seen that there are not many comments for the third version of the PPR's design. All the comments related to the second version of PPR were reviewed and thus, the proper PPR design for the third version was developed. There are only several comments given by Expert B that need to be modified by the researcher, especially those regarding the criteria of PPR in Week 3. The criteria of "Hardware and/or Software Recognition" and "Proficiency in Using Equipment and/or Software" are overlapping; hence, the researcher differentiated it by adding the "Implementing Engineering Design" criterion that is more focused on the hardware and software design development. In addition, another criterion was also included in PPR (Week 3): "Hardware and/or

Software Tools Usage" that assesses the correctness and relevancy of the equipment connection or coding to address the problem.

Finally, after the correction and modification of the third PPR's design were made, the fourth version of the PPR was again reviewed and finalised by Expert B. Besides, the fourth version of the PPR design was also reviewed again by Expert A. Thus, on 30 September 2014, both of the experts agreed and approved the design of PPR (Version Four). This validation is in terms of the PPR's content in assessing the problem solving skills in the PB Lab course. A Content Validation Form was given to the two experts to be completed and signed, which is one of the validation procedures. This form can be referred to in the Appendix M and the approved final Problem solving Process Rubric's design can be referred to in the Appendix K.

6.4 Construct Validity

Another important validity aspect emphasised in developing the valid Problem Solving Process Rubric (PPR) is in terms of construct validity. This validity aspect focuses more on the relevancy of content in the rubric and the knowledge and skills represented in the assessment itself (Nicholson *et al.*, 2009; Moskal and Leydens, 2014). Again, one of the most effective routes to validate the rubric's construct is by determining the experts' view (Nicholson *et al.,* 2009).

In this study, an expert who is a senior lecturer from the Department of Test and Measurement, Faculty of Education was responsible to review the PPR's (fourth version) construct after the PPR's content was validated. Expert C is a senior lecturer from the Department of Education Foundation and Social Science, Faculty of Education (FP), UTM. Her 23 years of teaching experience and 10 years of experience in assessment instrumentation development underpin her expertise in the assessment in education context; she was appointed to the position of Project leader for the Instrumentation Development in the FP. Premised on the foregoing, she was chosen as an expert in this study to review and determine any construct of the PPR design that is not well developed or not aligned with each other. The details of this construct validation are as in Table 6.6.

Table 6.6: Construct Validation Details

No.	Subjects	Details
1.	Experts	C
2.	Types of Validation	Construct Validity
3.	No. of validation process	2 times
4.	Date of validation	Cycle 1: 7 October 2014 Cycle 2: 12 October 2014

Importantly, the construct validation process was conducted after Expert A and Expert B validated the contents included in the PPR's design. Expert C is responsible for determining how the PPR was constructed; she reviewed all the analysis made as presented in Chapter 5. Expert C also reviewed the triangulation process done by the researcher in ensuring all the collected data in Chapter 5 are aligned with one another. Finally, on 12 October 2014, the construct of the Problem Solving Process Rubric (PPR) was finalised and validated by Expert C. The Validation Form completed by Expert C is contained in Appendix O and the final design of PPR is also in the Appendix P.

6.5 Verification from Industry

Verification process have been done by researcher after the final PPR been developed. Three experience engineers from different company and specialization participated in this phase. They need to complete a PPR Criteria Checklist form which include the criteria from the PPR. The objectives of this phase was to verify whether the PPR's content were align with the problem solving processes occurred in the real engineering industry. The details of the engineers were reported in Table 6.7. The results obtained from the PPR Criteria Checklist are as below:

Table 6.7: PPR Criteria Checklist

Criteria \ Engineers	A	B	C
Defining the Enginnering Problem	1	1	1
Applying Engineering Fundamental Knowledge	1	1	1
Identifying and Interpreting Relevant Information	1	1	1
Developing the Plan	1	1	1
Hardware and/or software Tools Usage	1	1	1
Implementing Engineering Design	1	1	1
Interpretation of Results	1	1	1
Evaluate the Solution	1	1	1
Communication	1	1	1
Fullfillment of Task	1	1	1

Note: 1 stand for Yes, 0 stand for No

Table 3.7 shows the results of the checklist completed by three engineers. A complete checklist included the problem solving processed assessed in the PPR, with a Yes-or-No scale, was given to the engineers to be rated whether the processes happened in their real workplace. Based on the result shows that all the problem solving processes stated in the rubrics were also happened in the real engineering workplace.

6.6 Conclusion

This chapter has presented the feedback and comments given by the experts in terms of the validity aspect of the Problem Solving Process Rubric's (PPR) design. Three experienced lecturers who have expertise in the PB Lab course conducted reviews on the development of the rubric and the PPR design. The expert review method was implemented during this phase; it gave the researcher an opportunity to properly determine the rubric's parts that needed to be reviewed before they were finalised. Although there are several comments given by the experts, the final feedback shows that all the experts agreed with the design of the Problem Solving Process Rubric (PPR), and they approved the design of the Rubric to be used for all the PB Lab contexts. Instead of that, a verification phase also been done after the final PPR been proposed. Three engineers have reviewed the PPR Criteria Checklist and the results found that the problem solving process from the PB Lab course also occurred in the real industry.

CHAPTER 7

SUMMARY, IMPLICATION AND RECOMMENDATION

7.1 Introduction

This chapter presents some discussion on the study conducted and the conclusion that can be drawn from its findings. Suggestions for further research, recommendations for practices and the implication of future research work in engineering education are also presented. As mentioned earlier, the aim of this study is to develop a valid Problem solving Process Rubrics (PPR) for a project-based laboratory course. The PB Lab course at the Faculty of Electrical Engineering (FKE) has been selected as a case study. The first objective of the research is to identify the problem solving process that occurs during the PB Lab course activities. The identified problem solving process serves as the foundation in designing the Problem solving Process Rubrics (PPR). The second objective is to construct the rubrics' criteria, descriptors, and levels of performances related to the problem solving process for inclusion in the PPR. Finally, the third research objective examines the validity of the PPR design which includes the contents and constructs.

7.2 Summary of Research Study

Problem solving is one of the important skills that must be acquired by all engineering graduates. The demands from the industry also show that this skill is needed in solving the complex real life problem. However, the concern is how to determine the level of our engineering students' competencies in solving problem. Hence, a valid and specific assessment tools are needed in order to assess the students' problem solving skills competency level.

As discussed earlier, previous researches are found to have limitation in assessing problem solving skills due to; (a) inaccuracy in the method of assessing the problem solving skill itself; and (b) lack of research in developing the assessment tool that focuses on a specific problem solving process. Based on these limitations, a Problem solving Process Rubrics (PPR) has been developed in this study that concentrates on a specific problem solving process particularly in a project-based laboratory course. As mentioned earlier, the PB Lab course at the Faculty of Electrical Engineering (FKE) UTM has been selected as the actual case to be analysed in achieving the objectives of this study. Since 2007, rubrics have been used as a tool to assess the achievement of the students' learning outcomes in the PB Lab. Through documents analysis, six PB Lab course outcomes (CO) are listed. It is found that the PB Lab COs, namely CO1, CO2, CO3 and CO4 stipulate the need for students to be able to solve complex engineering problems. However, as highlighted in Chapter 3, problems occur when the available PB Lab rubric's criteria are found to have limitations in measuring the students' problem solving skills. This is due to the limited number of criteria listed in the PB Lab rubrics that assesses problem solving skills. Moreover, there are also misalignment issues between the assessment criteria listed in the previous PB Lab conduct in terms of rubrics and learning outcomes (Bahri *et al*., 2012).

This study aims to develop a valid rubric, namely the Problem solving Process Rubrics (PPR), which focuses on assessing students' problem solving skills in the PB Lab course. It is important to note that although the main research objective is to develop the PPR, the systematic process of constructing the PPR on the aspect of criteria, descriptors and levels of performances has been thoroughly explained in Chapter 4 until 6. This portrays the uniqueness of this study that reveals the systematic process of constructing and validating the PPR using sets of data and analyses. In designing the PPR, Mertler's (2001) rubric development models have been referred to as guideline. In developing the PPR, this study is divided into three phases as follows:

a. Phase I: Identification of problem solving process that occurred in the PB Lab course.
b. Phase II: Development of Problem Solving Process Rubric (PPR)
c. Phase III: Validation of Problem Solving Process Rubric (PPR)

7.2.1 Identification of Problem solving Process in the PB Lab Course

The first part of this study involves determining the problem solving process that occurs in the PB Lab, as part of the course activities. As a result, five main problem solving processes have been identified to have occurred from the first until the fourth week of the PB Lab course. The processes are identified based on observation and Interview I data collection, as follows:

a. Problem Identification
b. Project Planning
c. Implementing Engineering Design
d. Project Analysis
e. Solution Evaluation

The problem solving process model proposed by Woods *et al.* (1997) has been referred to as a guideline during the observation and interview sessions. Both results from the observation and interview are analysed using thematic analysis technique until the final themes arise and are validated using the percent agreement measurement. Table 7.1 shows the summary of the themes related to the problem solving processes in the PB Lab course that has been determined. In the four weeks duration of the PB Lab course, the problem solving processes are found to be consistent in terms of occurrence across all laboratories, regardless of the project given to the students.

Table 7.1 Main themes and sub-themes related to the problem solving processes in the PB Lab course

Problem-solving Process	Week 1	Week 2	Week 3	Week 4
Problem Identification				
Understand the problem	√	√		
Applying Basic Knowledge	√	√		
Information Searching	√	√		
Project Planning				
Plan the procedure for solution		√		
Equipment/Software Recognition		√		
Applying Basic Knowledge		√	√	
Information Searching		√	√	
Implement the Plan			√	
Implementing Engineering Design				
Implement the plan			√	
Check the plan			√	
Project Analysis				
Collect output data			√	
Analyse output data			√	
Solution Evaluation				
Present the solution				√

7.2.2 Development of Problem solving Process Rubrics (PPR)

Phase II is an important phase of the study as it pertains to the design and construction of the first version of the Problem solving Process Rubrics (PPR). The objective of the rubric is to assess the problem solving skills among engineering students in the PB Lab course. It is important to highlight again that Metler *et al.* (2001) rubric development model has been referred to in this PPR development phase. Three main parts of the rubrics design are; (a) criteria; (b) descriptors and (c) level of performances.

In developing the rubrics' criteria, the problem solving processes identified in Phase I of this study are used. The processes are included as the main assessing criteria for the PPR design. To select the sub-criteria under each main criterion, three types of qualitative data from these resources have been used: (a) Phase I, (b) Interview II; and (c) Documents. These data have been analysed and triangulated using checklists to determine the relevant and dominant criteria. The identified sub-criteria are discussed in Section 5.3 of this study. All the main criteria and sub-criteria are divided and spread over four weeks of the PB Lab course. This is because several of the criteria listed are only applicable in certain weeks during the PB Lab course conduct.

The importance of the criteria in the rubrics' design cannot be denied. Through the rubrics, students can get a clearer picture on the course's intended learning outcome; what they are expected to achieve at the end of the PB Lab. In many cases, students have "no idea" on what they need to improve in learning (Lane *et al.,* 2015). Hence, by including the relevant criteria required in the learning outcomes in the PPR design, students among other factors will improve their learning. Besides, according to Brookhart (2013), "effective rubrics do not list all the possible criteria; they list only the right criteria for the assessment purpose". To be effective, Brookhart (2013) stresses that only definable and observable criteria of rubrics should be selected. This will help lecturers assess and observe students, especially in terms of subjective skills such as problem solving during the learning activities.

Therefore, to ensure the PPR's design constructed is based on the applicable criteria, its design has been divided into 4 parts according the week number i.e. Week 1, Week 2, Week 3 and Week 4 of the PB Lab course. Under each of the criteria assessed, relevant descriptors have been developed to represent the qualities of the students' performances. These descriptors are designed and written based on the dominant and common problem solving process assessed by other educators. The development of these descriptors is also based on the students' observable reactions recorded in Phase I data, and supported by the feedback obtained from the interview session with the PB Lab facilitators as well as the documents obtained. The verbs used in the descriptors are also based on the Blooms Taxonomy Action Verbs in Appendix L. In developing the level of performances, the results from interview II and documents have been used. The results obtained from interview II, indicate the need for more rating scales among PB Lab facilitators in order to avoid misconception on their perception towards rubric ranking which has been reported in Bahri *et al.* (2012). In this study, four levels of performances (Exemplary, Proficient, Developing, Need Improvement) which consist of six rubric scales (5 to 0) have been developed. The choice of the levels' construct is based on the three data that have been collected, as mentioned earlier. Specifically, the levels of students' performances are set in the range of 5 (Exemplary) followed by 4 to 3 (Proficient), 2 to 1 (Developing) and 0 (Need Improvement). The selection of the 6-scales is based on its suitability for the descriptors described in the PPR. Finally, the first draft of the Problem solving Process Rubric (PPR) is developed and can be referred to in Appendix H.

7.2.3 Validation of Problem solving Process Rubrics (PPR)

In addition to the development of the PPR, the validity of its design is also important. Hence, the objectives of Phase III is to examine the validity of the PPR design including the contents and constructs in assessing problem solving skills for the PB Lab course. In this phase, the experts review method has been implemented to verify whether the PPR's content measures the required problem solving outcomes that it intends to measure and to check whether all the important aspects of the problem solving outcomes can be evaluated through the PPR. Three experts have reviewed and validated the PPR from the first until the fourth version of its design. The experts review method has helped to get more data in the form of feedback. The feedback obtained has revealed errors in the initial PPR design on the aspect of the terms, ranking and verbs used as reported in Chapter 6. The finalised proposed Problem solving Process Rubric (PPR) is in Appendix P while further details on it will be discussed in the following section. The criteria of the PPR have been verified by the industry which reveals their relevance to the actual problem solving process at the engineering work place.

7.2.4 Final Version of Problem Solving Process Rubrics (PPR)

As stated earlier, the main aim of this study is to design a valid Problem solving Process Rubric (PPR) as a formative assessment tool in assessing students' problem solving skills in a project-based laboratory context. In developing the PPR, Mertler *et. al.* (2001) step-by-step rubrics development model has been used as reference. The development process encompasses selecting the outcomes that need to be assessed and identifying the relevant criteria, descriptors, and levels to be included in the rubric followed by the validation process. Although Mertler *et al*. (2001) rubrics development process has been used as reference in this study, further detailing is necessary in designing the proposed PPR which has resulted in its step-by-step development that is presented at the end of this study as a contribution.

The processes involving the step-by-step development of the PPR are as follows:

a. Determine the course outcomes (CO) related to the problem solving skill.
b. Define what problem solving skill is required in the course.
c. Observe students' learning activities in the course to determine whether the problem solving process is included.
d. Identify students' specific attributes or performances (good or not-so good).
e. List out all problem solving process that has been observed.
f. Develop criteria: Triangulate and align the problem solving process observed with the problem solving outcomes stated in the CO.
g. Develop descriptors: Divide the levels into three basic levels (good, middle, poor) and describe the good and the poor students' performance in problem solving.
h. Develop levels: Review the basic levels at the descriptors, add the levels if needed.
i. Complete all the rubrics' criteria, descriptors, and levels.
j. Validate the rubric and revise if necessary.

Finally, the final version of the Problem solving Process Rubric or known as PPR is constructed and validated by the chosen experts and ready to be implemented. Table 7.2 presents the criteria assessed in the PPR and their meaning. The definitions that are based on the data collected in Phase I and the EAC program outcomes (PO) are presented to clarify the terms used in the PPR design.

Table 7.2: The Definitions of the PPRs' Criteria

No.	PPRs' Criteria	Definition
1.	Defining the Engineering Problem	Ability to identify and explain issues and objectives of a problem.
2.	Applying Engineering Fundamental Knowledge	Ability to identify and apply previous fundamental knowledge to solve a problem.
3.	Identifying and Interpreting Relevant Information	Ability to identify, interpret and relate the information obtained to solve a problem.
4.	Developing the Plan	Ability to plan and identify a suitable framework or steps to solve a problem.
5.	Hardware and/or Software Tools Usage	Ability to identify and create equipment connection and coding development to solve a problem.
6.	Implementing Engineering Design	Ability to design a solution that meets a given specification.
7.	Interpretation of Result	Ability to analyse and interpret the results obtained.
8.	Evaluate the Solutions	Ability to explain and demonstrate a process and reason for a solution.
9.	Communication in Group Work	Ability to interact within group members.
10.	Fulfilment of Task	Ability to fulfil a task given.

7.3 Future Research

Based on the findings of this study, several suggestions for future research are listed for improvements.

i. This study only focuses on one of the complex cognitive processes which is problem solving. Further studies should also be done for other processes in complex cognitive such as skills to critically think about some issues or skills to transform prior knowledge into creative works skills. According to Moreno (2010), the skills in complex cognitive processes explain how students make sense of new knowledge by trying to relate it to the prior knowledge stored in the students' long-term memory. These skills are important and need to be acquired by students especially in engineering context (Idrus, 2015; Darling-Hammond *et al*., 2010).

ii. This study only highlights problem solving skills in the context of a Project-based Laboratory (PB Lab). Therefore, the construct of the PPR is also based on the number of weeks of the PB Lab course conduct. Hence, for the findings to be implemented and relevant to other institutions it is recommended that the same PPR's criteria are applied in other instructions; but modification must be made, especially in terms of weeks included in the PPR. The weeks can be changed according to the laboratory context as long as the problem solving processes that occur are the same.

iii. The processes included in this study focus on selecting the outcome of problem solving to be assessed until the validation process of the PPR's design. Further work is needed to review the PPR design on the aspect of reliability, to identify the consistency of the students' marks obtained when rated. According to Bresciani *et al*. (2009) and Stellmack *et al.* (2009), reliability is one of the important aspect in rubrics measurement that must be identified. This is due to the function of the rubrics itself which is commonly used to assess students from variety of courses and across problems (Bresciani e*t al*., 2009). Thus, to determine the consistency of the students' marks, it is recommended that the PPR design is implemented in a real PB Lab setting, and an "interrater agreement" measurement can be used in evaluating the reliability of the PPR.

7.4 Recommendations for Practices

As stated, the main objective of this study is to develop a valid Problem solving Process Rubric (PPR) that can assess students' problem solving skills effectively in the PB Lab course. However, in the process of achieving the objective of the study three outcomes have been identified which are: (a) the problem solving processes in the PB Lab course; (b) the Problem solving Process Rubric's (PPR) design; and finally (c) the step-by-step process of problem solving rubric development. These three outcomes can be reviewed and implemented by other researchers or institutions. For example, the proposed framework of problem solving rubric development can be referred to by others in designing a problem solving rubric for their courses especially the laboratory courses. Besides, even though this study focuses more on the context of the PB Lab course, the following recommendation could be applied to other project-based laboratory courses that assess the problem solving skills.

Some recommendations for practice are:

(i) Alignment between Assessment, Learning Outcomes and Teaching and Learning (T&L) Practices

In developing a valid and effective assessment tool, the triangulation between the T&L practices, learning outcomes and the assessment itself should be aligned to one another. This refers to the constructive alignment proposed by Biggs (1996). According to (Biggs, 1996), if the learning outcomes focus on students' problem solving skill, the T&L pedagogy must also be tailored to lead students towards that skills. One of the T&L strategy deemed suitable is the project-based learning as discussed in this study. Here, the role of assessment is to assess the right learning outcomes so that the results can reflect the real achievement of the students in solving problems. In this study, to ensure that the PPR design is valid and able to assess the right problem solving outcomes, the actual problem solving process that occurs in the PB Lab course is first identified. This is to ensure that the T&L pedagogy implemented can drive the students to become good problem solvers. This has been discussed in detail in Chapter 4. In addition, the PB Lab T&L activities have also been observed. In this case, any students' attributes related to problem- solving have been determined and gathered as the main data in developing the Problem solving Process Rubric (PPR) as presented in Chapter 4 and 5.

(ii) Processes in Developing Rubric Design

Developing rubrics may be easy for those who are already experts in the field. But, for new lecturers, a proper step-by-step process of rubric development may help them as a reference or guideline. Some of the processes that have been discussed in this study are those presented by Mertler (2004), Arter and Chappius (2007) and Andrade (2014). These processes can guide the lecturers to construct a rubric systematically by determining the relevant rubric's criteria, descriptors and levels of performances, so that the required outcomes can be assessed. The findings of this study have been presented in section 7.3, which highlight the step-by-step process of developing the proposed PPR in the PB Lab context.

(iii) Engaging Students with Rubrics Assessment

Rubrics can be an effective assessment tool for students if they are aware of the criteria and what they will be assessed on at the beginning of the class. Lecturers should explain all the criteria listed in the rubrics used in class to students. This includes showing the descriptors and the levels that may differentiate excellent and weak students as suggested by Piquer (2015). By doing this, students would be motivated to perform well based on the criteria listed. According to Andrade (2000), a well-designed rubric that describes both the positive and negative aspects of the students' performance can give valuable information for students to know their potential.

7.5 Conclusion

As a conclusion, this study is important to instil the need for valid problem solving assessment tools in assessing engineering students' problem solving skills, which can specifically measure the students' competency levels in problem solving as emphasised in the EAC program outcomes. A specific and valid problem solving assessment tool can provide some indication to the stakeholders on the strength and limitation of our engineering graduates which can be continuously improved through proper planning of the instructional methods. In a project-based learning teaching and learning approach, students can enhance their problem solving skills in solving real and complex issues. This study has found that the effectiveness of the project-based learning in the laboratory can be improved by using proper problem solving assessment tools like rubrics which can specifically rate the students' problem solving skills. Finally, it has verified that the PPR is indeed relevant in assessing the students' problem solving skills. The criteria proposed in the PPR can be used not only in the PB Lab context, but also in determining the students' level of competency in problem solving in any electrical engineering project-based laboratory course. A summary on the step-by-step process in developing the PPR has also been shared. It is hoped that the PPR design and the process of developing it, as being meticulously reported, can help other engineering educators to develop valid rubrics that is capable of assessing specific problem solving skills effectively, especially in engineering project-based laboratory courses.

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APPENDIX A

Example of Field Notes Table

OBSERVATIONAL FIELD NOTES: PROBLEM-BASED LABORATORY (PBLAB) COURSE

Objectives:

1) To understand *how the PBLab activities are conducted.*
2) To determine the *steps in the PBLab activities that involves the problem-solving skills.*
3) To determine *how the PBLab facilitators use the rubric assessment tools* in evaluating the students in real PBLab practice.

WEEK: 1

Setting:
Topic:
Observer: Ayuni
Role of observer:
Time/Date:
Facilitator involved:
Length of observation:
Number of students attends:

Observation notes	Descriptions	Sub-codes	Codes/Sub-themes

Example of Observation Data

OBSERVATIONAL FIELD NOTES: PROBLEM-BASED LABORATORY (PBLAB) COURSE

Objectives:

1) To understand *how the PBLab activities are conducted.*
2) To determine the *steps in the PBLab activities that involves the problem-solving skills.*
3) To determine *how the PBLab facilitators use the rubric assessment tools* in evaluating the students in real PBLab practice.

Week: 1

Setting: Advance Power Laboratory (PO8)

Topic: Topology of Electrical Distribution System

Observer: Ayuni

Role of observer: Direct observer

Time: 8am, 19 November 2012

Facilitator involved: A: Dr. Saifulnizam

Length of observation: 3 hours

Number of students attends/group: 5 students (2 boys, 3 girls)

Observation Notes	Descriptions	Sub-codes	Codes/Sub-themes
This lab was been observed on Monday,19 November 2012 and all the students met at the Advance Power Lab (APL) PO8 block. The facilitator for this section 1 group is Dr. Saifulizam. The problem or the project of this lab session was regarding the Power Handling Capacity in Three Phase System. The major task of this lab session was to dedahkan to the students the characteristic of real power flow at the transmitter line, to find out the available methods for controlling the direction of the power flow and do some experiments			

Example Form of Agreement

CONTENT VALIDATION FORMS

Name: Dr Hadijah Jaffri   Position: Senior Lecturer   Email: hadijahjaffri@utm.my

Department/Faculty: Department of Foundation Education and Social Science   Teaching experience: 9 years

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Direction:
Fill in the form below by choosing either A (Agree) or NA (Not Agree) by ticking (√) at the given column. This is in order to verify whether the items stated are reflected by code. If you have questions or recommendation on any items of this form, kindly leave a comment at the remarks column.

WEEKS	ITEMS	CODING	#	A	NA	REMARKS
Week 1	The facilitator and the students discussed the problem/project given together. Then, the students discussed with their group members in front of the facilitator.	Problem Identification *(discuss, problem/project given)*	1	√		
	The facilitator brief some concept about the problem presented to the students.	Problem Identification *(brief, concept, problem)*	2		√	Revise sentence. *The facilitator explained some relevant concepts briefly related to the problem assigned to the students.*
	The students found the information by using the computers.	Information Searching *(computer , found information)*	3	√		Does it have to be limited to computer only?
	The students started to discuss with their group mates regarding the information that they found. Some students talked about the information that he/she obtained while others just kept quiet.	Interpretation of Information *(discuss, information)*	4	√		
	The facilitator asked the students about their understanding on the problem/project given one-by-one.	Problem Identification *(ask, understanding)*	5	√		Does it mean that the facilitator will ask the students individually?
	The facilitator spent about one hour discussing and explaining to the students about the problem. The students wrote something on paper and kept reading the problem statements given.	Problem Identification *(discussing, explaining, writing, reading problem statement)*	6		√	There are two categories of individuals: facilitator and students. Which one is the main focus here?
	The facilitator explained and asked the students the basic concepts that they have acquired in order to solve the problems.	Applying previous knowledge *(ask, explain, basic concept)*	7		√	Omit "the". Basic concepts refer to engineering concepts or it could be related to non-engineering concepts?
	The students went to the computer laboratory at the PO7 block to search for information. Then, the students came back to the laboratory and discuss with their group members the information that they have found.	Information Searching *(computer lab, discuss)*	8	√		Does it have to be specified to one place?
	The facilitator started asking the students one-by-one about the information that they found. Some students can explain what she has found, but others just repeat what their friends explained.	Interpretation of Information *(ask, information, explain)*	9	√		*Some students can **explain** what they have found, but others just repeat what their friends explained.*

APPENDIX C

APPENDIX D

Example of Interview Protocol

Interview Protocols for PBLab Facilitators

Thank you for agreeing to this interview. The purpose is to look into your views of problem solving skills as well as to determine the way you assess students in PBLab course using rubrics especially for problem solving skills assessments.

A. <u>Personal background &</u>

1. Would you tell me your name and your department?
2. How long have you facilitates students in the PBLab course?

B. <u>Understanding assessing students using rubrics.</u>

1) **As you know, the students are been given 4 weeks to solve their project/problem in this PBLab course, as a facilitator, how did you facilitate them during the PBLab lab session from week 1 until week 4. Explain each of weeks.**
2) Have you ever gone through the rubrics training before this?
3) Based on your understanding, what are rubrics assessments?
4) Based on your experiences, how you assessed students in PBLab course using rubrics?
5) How you differentiate the students' marks individually using rubrics?
6) As you know, the existing PBLab rubrics have 4 level of students achievements which is level 4(excellent), level 3(good), level 2(fair) and level 1(poor). Based on this, how did you differentiate between these rankings? What kind of component/elements that you used in order to differentiate it?
7) Have you ever feel confuse using this rubrics?
8) What is your suggestion in order to improve this rubrics design?

APPENDIX E

Examples of Rubrics Feedback Form

1-

Rubric feedback form

Instructions: Please respond honestly and constructively to the questions below by circling the responses you most agree with and write brief comments.

1. On the scale below, please rate the ***clarity* of descriptors** in the rubric.

1	2	3	4	5
Totally unclear	Somewhat unclear	Mostly clear	Very clear	Extremely clear

2. On the scale below, please rate the ***distinction of level*** in the rubric.

1	2	3	4	5
Totally unclear	Somewhat unclear	Mostly clear	Very clear	Extremely clear

3. On the scale below, please rate the ***clarity* of criteria** in the rubric.

1	2	3	4	5
Totally unclear	Somewhat unclear	Mostly clear	Very clear	Extremely clear

4. Overall, **how *easy*** did you find to use the rubric for your class assessment (which includes log-book evaluation, written report of a project/assignment and presentation)?

1	2	3	4	5
Extremely difficult	Somewhat difficult	Mostly easy	Very easy	Extremely easy

5. Overall, **how *useful*** was the rubric in helping you of the following (choose any which relevant to you and rate it)

Aspects	1 Totally useful	2 somewhat useful	3 mostly useful	4 very useful	5 extremely useful
a. Assigning marks					
b. Itemising criterion for assessment					
c. Keeping track of individual and group marks					

6. What do you find **most *useful*** about the rubric? (Please list one or two specific examples)

7. What do you find **most *difficult*** about the rubric? (Please list one or two specific examples)

8. How could the rubric to be improved? (Please give one or two specific suggestions)

Previous PB Lab Rubrics (Semester 2013/2014)

FKE-4722-06 (03)

4th YEAR LABORATORY - INDIVIDUAL IN-LAB ACTIVITIES EVALUATION

Laboratory: ____________________ Program: ____________ Section no: ____________ Group no.: __________

Title of Project/ Problem: ______________________________ NAME: ______________________

No.	Criteria	Excellent 4	Good 3	Fair 2	Poor 1	Individual Score			
						W1	W2	W3	Total
1.	Punctuality	Arrive on time, fully utilizing lab hours.	Arrive on time, but not fully utilizing lab hours.	Up to 5 minutes late.	More than 10 minutes late.				
2.	Discipline *Dress codes, laboratory regulation & safety*	Conform to lab's dress code and all lab regulation & safety.	Conform to lab's dress code and nearly all lab regulation & safety.	Conform to lab's dress code and nearly all lab regulation but with minor flaws in safety.	Does not fully conform to lab's dress code or major flaws in lab's safety.				
3.	**Proficiency in Using Lab Equipment and/or Software** *The student demonstrates skill and understanding in using lab hardware and software*	Able to sets up equipment and collects data in an **efficient** manner. Fully utilise the software tools to analyze and display the data collected	Able to sets up equipment and collects data in an **efficient** manner **but not** fully utilise the software tools to analyze and display the data collected	Able to sets up equipment and collects data in **less efficient** manner **and not** fully utilise the software tools to analyze and display the data collected	Not able to set up equipment and utilize the software tools.	___ x 2 =___	___ x 2 =___	___ x 2 =___	___ x 2 =___
4.	Role play *How the student carries himself in a group, dominance, fulfils role's duty* ***(through observation and interview)***	Performs all duties of assigned team role.	Performs nearly all duties of assigned team role..	Perform **little duties** of assigned team role.	Perform **minimally or very little of** any duties of assigned team role.	___ x 1.5 =___	___ x 1.5 =___	___ x 1.5 =___	___ x 1.5 =___
*5.	Knowledge on problem/project ***(Through interview session)***	Able to give **thorough** explanation on the problem/project **and** the work assigned	Able to give **some** explanation on the problem/project **and** the work assigned	Able to give **some** explanation on the problem/project **but not** the work assigned	Not able to explain the problem/project **and** the work assigned	___ x 2 =___	___ x 2 =___	___ x 2 =___	___ x 2 =___
	Total Scores (30 %)								

MEMBER'S NAME:	M3 =
M1 =	M4 =
M2 =	M5 =

Facilitator: ______________________ **Signature:** __________________ **Date:** __________

4^{th} YEAR LABORATORY - PEER EVALUATION FORM

Laboratory: ______________________________Program: _________ Section no:______Group no.:_________

Title of Project/ Problem:____

MEMBER'S NAME: **(According to Member's Number as assigned in grouping list)**	M3 =
M1 =	M4 =
M2 =	M5 =

Please use the following form to assess the contributions of everyone in your group. Using the following scale, rate each member of your group (1,2,3, and 4 as you have indicated above):

5 = strongly agree → 1 = strongly disagree.

	Criteria	**Group members**				
		M1	**M2**	**M3**	**M4**	**M5**
	Group Contribution					
1.	Hands in all given tasks or assignments **on time**					
2.	Contributes a great deal of relevant information					
3.	Communicates and shares all information with the group					
	Cooperation Within Group					
1.	Always cooperates					
2.	Balances between talking and allowing others to talk					
3.	Always considers all view points					
	Responsibility to Group Members					
1.	Perform all duties					
2.	Always does assigned work without being reminded					
	Total points (40)					

Your Name: ______________________________

Signature: ______________________________ Date: ____________________

Note: *Please submit within a week after your oral presentation day (i.e. within the 5^{th} week) into the corresponding peer review box. No marks for student who submit late.*

FKE-4722-09(01)

4th YEAR LABORATORY - GROUP REPORT EVALUATION

Laboratory: ____________________ Program: ______________ Section no: __________ Group no.: ____________________

Title of Project/ Problem: ____

MEMBER'S NAME:	M3 =
M1 =	M4 =
M2 =	M5 =

No.	Criteria	Excellent 4	Good 3	Fair 2	Poor 1	Score
1.	Abstract *Short statement of purpose of work, pertinent conditions, results in brief*	The abstract is generally solid (all main points present).	Only two main points of the abstract is present	Only one main point of the abstract is present	All main points of the abstract are not present	
2.	Introduction *Background, problem solving approach, objectives*	Presents a concise lead-in to the report.	Gives too much information, more like a summary.	Gives very little information.	Does not give any information about what to expect in the report.	
3.	Procedures *Steps taken, method used, circuit diagrams, design calculations, flow charts etc.*	Presents easy-to-follow steps which are logical and adequately detailed.	Most of the steps are understandable; some lack detail or are confusing.	Some of the steps are understandable; most are confusing and lack detail.	Not sequential, most steps are missing or are confusing.	
4.	Data & Results *Results in the form of data, graphs etc.*	Data table and graph neatly completed and totally accurate.	Both accurate, some ill-formed characters.	Both complete, minor inaccuracies and/or illegible characters.	Data table and/or graph missing information and are inaccurate.	___ x 2 =
5.	Discussion *Points of discussion (significance of results, analysis, comparisons, speculations etc.)*	All points of discussion on the results obtained covered and elaborated.	Some points of discussion on results obtained covered and elaborated.	Some points of discussion on results obtained covered but not properly elaborated.	Only a few points of discussion on results obtained covered and not properly elaborated	___ x 3 =
6.	Conclusion *Provide answers to objectives stated earlier*	The closing paragraph summarizes and draws a clear and well developed conclusion	The closing paragraph summarizes and draws a sufficiently supported conclusion	The closing paragraph attempts to summarize but draws a weak conclusion	Concluding paragraph is not apparent	
7.	References	Five or more well chosen sources are used.	Four appropriate sources are used.	Only three appropriate sources used.	Two or less appropriate sources used	
8.	Grammar & Spelling	All grammar and spelling are correct.	Only one or two errors.	More than two errors.	Very frequent grammar and/or spelling errors.	
9.	Attractiveness	Word processed, clean, pages numbered, stapled, illustrations and appendix provided (if appropriate).	Word processed, clean, and stapled, illustrations and appendix provided (if appropriate).	Word processed, print too small or too large, papers stapled together.	Hand written, loose pages.	
10.	Timeliness	Report handed in on time.	Up to two days late.	Up to one week late.	Report handed in more than one week late.	
	Total points					
	Total (20%) (*Calculation formula:* maximum score x $\frac{20}{52}$)					

Facilitator: ____________________ Signature: ____________________ Date: ____________________

4th YEAR LABORATORY - LOG BOOK EVALUATION

Laboratory: ______________________________Program: ___________________ Section no:_______________Group no.:_____________

Title of Project/ Problem:____

MEMBER'S NAME:	M3 =
M1 =	M4 =
M2 =	M5 =

No.	Criteria	Excellent 4	Good 3	Fair 2	Poor 1	Score			
						W2	W3	W4	Total
1.	Number of entries	At least three times a week	Twice a week	Once a week	No entries at all				
2.	Formatting *Handwritten in ink, corrections properly made, group member initials on each page, pages properly numbered and dated, no pasting, stapling etc.*	Follows all designated formatting guidelines	Follows most (75%) designated formatting guidelines	Follows a few (50%) designated formatting guidelines	Lacks many elements of correct formatting				
3.	Content **may** include: *Minutes of group meetings, items of discussion, action items, concepts, sketches, preliminary ideas, sketches of circuit design, flow charts etc., experimental procedures, experimental data, output etc., rough calculations*	All aspects of the problem or project have been properly logged	Most aspects of the problem or project have been properly logged	At least 80% of the aspects covering the problem or project have been logged	Less than 80% of the aspects covering the problem or project have been logged	____ x 2 = ____	____ x 2 = ____	____ x 2 = ____	
4.	Management *Group member meeting attendance, appointment of group manager (different person for each problem/project), log book entries by different group member (different handwritings)*	All management aspects have been thoroughly fulfilled	Two of the management aspects have been thoroughly fulfilled	Only one of the management aspects have been thoroughly fulfilled	None of the management aspects have been thoroughly fulfilled				

FKE-4722-08 (01)

4th YEAR LABORATORY – GROUP PRESENTATION EVALUATION

Laboratory: ______________________________ Program: _____________ Section no: _____________ Group no.: __________

Title of Project/ Problem: ____

No.	Criteria	Excellent 4	Good 3	Fair 2	Poor 1	SCORE
	Presentation					
	Organisation	Presentation is clear. Can easily be followed.	Presentation is generally clear with a few minor confusing points.	Presentation can be followed but with effort.	Presentation is very confusing and not clear at all.	
1.	Style in presenting scientific results	Level is appropriate, speakers are easy to understand.	Level is generally appropriate, some problems in understanding a speaker.	Presentation is too informal or unprepared, information being read, speakers are difficult to understand.	Level is inappropriate, information being read, speakers can't be understood.	
	Visual Aids (Power point presentation)	Aids prepared in professional manner with main points that stand out.	Aids contributed but not all material is supported by aids. Proper font size	Aids are poorly prepared or used inappropriately. Font size is too small.	No aids are used or very poorly prepared.	
2.	**Introduction**	Discuss purpose of work with relevant background information.	Some discussion on purpose of work, missing some background information.	Some discussion on purpose of work, no background information.	Little or no information on purpose of work, no background information.	
3.	**Summary of Methods**	Design of simulation, programming, experiment and methods used are clearly stated and described.	Design of simulation, programming, experiment and methods used are described with some items missing or insufficiently described.	Methods used are insufficiently explained with large gaps in information.	Methods used are not explained at all.	_____ x2 = _____
4.	**Discussion of results and conclusions**	Results and conclusions are clearly stated. Thorough discussion on what results mean and implications of results. Provide consistently accurate information.	Description of results is generally clear. Some discussion on what results mean and implications of results. No significant errors are made.	Little discussion on what results mean and implications of results. Enough errors are made to be distracting, but some information are accurate.	Discussion on results is very difficult to follow. No discussion on meaning of results. Information is so inaccurate that makes the presentation unreliable.	_____ x 3 = ---------
5.	**Project Accomplishment**	Results show that student have managed to achieve all the objectives.	Results show that student have put some effort to achieve the objectives.	Results show that student did not put enough effort to solve the problem.	No evidence of any work being done from the presented results.	
	TOTAL SCORES (10%)		*(Calculation formula maximum score 40 points/4)*			

INDIVIDUAL PRESENTATION EVALUATION						Individual Score				
No.	**Criteria**	**Excellent 4**	**Good 3**	**Fair 2**	**Poor 1**	**M1**	M2	M3	M4	M5
1	**Pace**	Speakers' pace is well planned for audience to understand.	Occasionally speaker's pacing is too fast or too slow, repetitive or skipping important details.	Most of the time speaker's pacing is too fast or too slow, repetitive or skipping important details.	Presentation is far too long or far too short, speaker generally are too fast or too slow.					
2	**Eye Contact**	Student maintains eye contact with audience, seldom returning to notes.	Maintains eye contact most of the time but frequently returns to notes.	Occasionally uses eye contact, but still reads mostly from notes.	No eye contact and only reads from notes.					
3	**Response towards audience**	Responds well to questions. Restates and summarizes when needed.	Generally responsive to questions.	Reluctantly interacts with audience. Responds poorly to questions.	Avoids audience interaction. Not responsive to group.					
4	**Attire**	Appropriately dressed for seminar	Acceptable	Clean and attractive but not proper for seminar	Poorly attired eg. Messy hair; dirty clothes, wearing slippers					
5	**Confidence**	Speak with confidence and able to handle audience easily.	Showing confidence most of the time	Some confidence, at times appears awkward.	Long pauses throughout presentation.					
Total Scores (10%)			*(Calculation formula maximum score 20 points/2)*							

MEMBER'S NAME:	M3 =
M1 =	M4 =
M2 =	M5 =

Facilitator: ____________________ **Signature:** ____________________ **Date:** ____________

APPENDIX G

Examples Problem solving Rubrics Gathered

Component	Sophisticated	Competent	Not yet Competent
Research & Design *Identifies project objectives based on general description and client requirements*	All important major and minor objectives are identified and appropriately prioritized.	All major objectives are identified but one or two minor ones are missing or priorities are not established.	Many major objectives are not identified.
Identifies relevant & valid information to support decision-making.	All relevant information is obtained and information sources are valid. Design recommendations are well supported by the information.	Sufficient information is obtained and most sources are valid. Design recommendations are mostly supported by the information.	Insufficient information is obtained and/or sources lack validity. Design recommendations are not supported by information collected.
Generation and analysis of alternatives.	Three or more alternatives are considered. Each alternative is appropriately and correctly analyzed for technical feasibility.	At least three alternatives are considered. Appropriate analyses are selected but analyses include some minor procedural errors	Only one or two alternatives are considered. Inappropriate analyses are selected and/or major procedural and conceptual errors are made.
Identifies relevant constraints (economic, environmental/ safety sustainability, etc)	All relevant constraints are identified and accurately analyzed.	Most constraints are identified; some are not adequately addressed or accurately analyzed.	Few or no constraints are identified or some constraints are identified but not accurately analyzed.
Generates valid conclusions/decisions	Recommended solution is based on stated criteria, analysis and constraints.	Solution/decision is reasonable; further analysis of some of the alternatives or constraints may have led to different recommendation.	Only one solution is considered or other solutions were ignored or incompletely analyzed. Many constraints and criteria were ignored.

Retrieved from: Universities of Pittinburgh

Component	Sophisticated	Competent	Not yet Competent
Team Work (Based on peer evaluation, observations of group meetings and presentation)			
Delegation and fulfillment of Responsibilities	Responsibilities delegated fairly. Each member contributes in a valuable way to the project. All members always attended meetings and met deadlines for deliverables.	Some minor inequities in the delegation of responsibilities. Some members contribute more heavily than others but all members meet their responsibilities. Members regularly attended meetings with only a few absences, and deadlines for deliverables were met.	Major inequities in delegation of responsibilities. Group has obvious freeloaders who fail to meet their responsibilities or members who dominate and prevent others from contributing. Members would often miss meetings, and/or deadlines were often missed.
Team morale and cohesiveness	Team worked well together to achieve objectives. Members enjoyed interacting with each other and learned from each other. All data sources indicated a high level of mutual respect and collaboration.	Team worked well together most of the time, with only a few occurrences of communication breakdown or failure to collaborate when appropriate. Members were mostly respectful of each other.	Team did not collaborate or communicate well. Some members would work independently, without regard to objectives or priorities. A lack of respect and regard was frequently noted.

Retrieved from: Universities of Pittinburgh

	Capstone	Milestones		Benchmark
	4	3	2	1
Define problem	Demonstrates the ability to construct a clear and insightful problem statement with evidence of all relevant contextual factors.	Demonstrates the ability to construct a problem statement with evidence of most relevant contextual factors, and problem statement is adequately detailed.	Begins to demonstrates the ability to construct a problem statement with evidence of most relevant contextual factors, but problem statement is superficial.	Demonstrates a limited ability in identifying a problem statement or related contextual factors.
Identify strategies	Identifies multiple approaches for solving the problem that apply within a specific context.	Identifies multiple approaches for solving the problem, only some of which apply within a specific context.	Identifies only a single approach for solving the problem that does apply within a specific context.	Identifies one or more approaches for solving the problem that do not apply within a specific context.
Propose solutions/hypotheses	Proposes one or more solutions/hypotheses that indicates a deep comprehension of the problem. Solution/hypotheses are sensitive to contextual factors as well as all of the following: ethical, logical, and cultural dimensions of the problem.	Proposes one or more solutions/hypotheses that indicates comprehension of the problem. Solutions/hypotheses are sensitive to contextual factors as well as the one of the following: ethical, logical, or cultural dimensions of the problem.	Proposes one solution/hypothesis that is "off the shelf" rather than individually designed to address the specific contextual factors of the problem.	Proposes a solution/hypothesis that is difficult to evaluate because it is vague or only indirectly addresses the problem statement.
Evaluate potential solutions	Evaluation of solutions is deep and elegant (for example contains thorough and insightful explanation) includes, deeply and thoroughly, all of the following: considers history of problem, reviews logic/reasoning, examines feasibility of solution and weighs impacts of solution.	Evaluation of solutions is adequate (for example contains horough explanation) and includes the following: considers history of problem, reviews logic/reasoning, examines feasibility of solution and weighs impacts of solution.	Evaluation of solutions is brief (for example explanation lacks depth) and includes the following: considers history of problem, reviews logic/reasoning, examines feasibility of solution and weighs impacts of solution.	Evaluation of solutions is superficial (for example, contains cursory, surface level explanation) and includes the following: considers history of problem, reviews logic/reasoning, examines feasibility of solution and weighs impacts of solution.
Implement Solution	Implements the solution in a manner that addresses thoroughly and deeply multiple contextual factors of the problem.	Implements the solution in a manner that addresses multiple contextual factors of the problem in a surface manner.	Implements the solution in a manner that addresses the problem statement but ignores relevant contextual factors.	Implements the solution in a manner that does not directly address the problem statement.
Evaluate outcomes	Reviews results relative to the problem defined with thorough, specific considerations of need for further work.	Reviews results relative to the problem defined with some consideration of need for further work.	Reviews results in terms of the problem defined with little, if any consideration of need for further work.	Reviews results superficially in terms of the problem defined with no consideration of need for further work.

Retrieved from: Association of American Colleges and Universities

Problem Solving Rubric

	4 Exemplary	3 Proficient	2 Developing	1 Needs Development	Comments
Define Problem	The group identifies the key elements of the problem and clearly outlines the objectives in an effective manner with no assistance.	The group identifies the key elements of the problem and clearly outlines the objectives in an effective manner with little assistance.	The group identifies the key elements of the problem and clearly outlines the objectives in an effective manner with assistance.	The group is unable to identify the key elements of the problem and/or the objectives without a great deal of assistance.	
Process	The group develops strategies that are insightful and use logical reasoning to reach accurate results with no assistance.	The group develops strategies that are insightful and use logical reasoning to reach accurate results with little assistance.	The group develops strategies that are insightful and use logical reasoning to reach accurate results with assistance.	The group is unable to develop strategies that are insightful and logical without a great deal of assistance.	
Evaluation	The group determines whether the results are accurate and reflects on any issues, mistakes, or misunderstandings encountered during the problem solving process with no assistance.	The group determines whether the results are accurate and reflects on any issues, mistakes, or misunderstandings encountered during the problem solving process with little assistance.	The group determines whether the results are accurate and reflects on any issues, mistakes, or misunderstandings encountered during the problem solving process with assistance.	The group is unable to determine the accuracy of the results and does not reflect on issues, mistakes, or misunderstandings without a great deal of assistance.	
Construct Representation	The group constructs a representation (model, drawing, verbal) that accurately reflects the problem and aids in solving the problem with no assistance.	The group constructs a representation (model, drawing, verbal) that accurately reflects the problem and aids in solving the problem with little assistance.	The group constructs a representation (model, drawing, verbal) that accurately reflects the problem and aids in solving the problem with assistance.	The group is unable to construct a representation (model, drawing, verbal) that reflects the problem without a great deal of assistance.	

Retrieved from: We-Impact

Student Name________________ **Course/Section**________________ **Date/Qtr**________________ **Overall Score**________

Component	1	2	3	4	
C.1 Use a logical problem-solving process when making decisions.					
a. Define the problem: ▪ Identifies a problem. ▪ Assesses the impact of the problem (i.e., on a community, personal, and group level).	Unable to identify and express problem. Difficult to understand.	Identifies problem on a superficial level. Unable to express problem clearly.	Identifies and expresses problemat a competent level.	Expresses problem to others in a clear and concise manner including the scope and impact of the problem (e.g., on the community, personal, and/or group level appropriately).	Pts.______

Component	1	2	3	4	
b. Gathers and analyzes data/facts from appropriate sources. ▪ Differentiates between facts and opinions. ▪ Able to use at least two sources. ▪ Able to isolate the variables that influence the problem.	Gathers irrelevant data. Relies upon opinions and/or incredulous source(s).	Uses both opinions and facts. Uses limited data with insufficient sources and/or from dubious source(s). Able to isolate some but not all variables that influence the problem.	Uses appropriate data and is able to differentiate between facts and opinions. Uses credible and sufficient sources. Able to isolate nearly all variables that influence the problem.	Demonstrates superior command of data collection and ability to discern the difference between fact and opinion while using ample sources. Able to isolate all variables that influence the problem and analytically describe the influence of each on the problem.	Pts.______

Component	1	2	3	4	
(Planning) c. Generates multiple potential solutions and identifies the best one. ▪ Describes each solution. ▪ Identifies strengths and weaknesses of each solution. ▪ Recognizes and does not use common reasoning errors (e.g., false cause, slippery slope, hasty conclusion, *ad populum*, appeal to tradition, etc.).	Unable to identify at least one solution and assess the strengths or weaknesses clearly; demonstrates reasoning errors. Unable to effectively plan a solution and/or corrective action.	Identifies at least two solutions and their strengths and weaknesses, but demonstrates one reasoning error. Partially able to effectively plan a solution and/or corrective action.	Clearly expresses at least two solutions to the problem while choosing the best solution based on the strengths and weaknesses provided while demonstrating no reasoning errors. Able to effectively plan a solution and/or corrective action.	Easily expresses problem to others in a clear and concise manner expressing the impact of the problem on the community, personal, and/or group level appropriately. Plan to solve the problem and/or take corrective action that is viable and likely to be successful.	Pts.______

Retrieved from: Marion Technical College

Example of Problem solving Process Rubrics (PPR) Ver. 1 (Week 1)

PROBLEM-SOLVING PROCESS RUBRICS
(WEEK 1)

Laboratory/Project Title:____________________________________Program/Section No. /Group. No.:____________Name: ________________________________

INSTRUCTION TO LAB'S FACILITATOR: Please WRITE the scores that you choose to complete this assessment form.

Criteria	Levels						Scores
	Exemplary	Proficient		Developing		Need Improvement	
	5	4	3	2	1	0	
PROBLEM IDENTIFICATION							
Defining the Problem/ Project	• Able to explain the problem/project issues and objectives clearly. • With no assistance.	• Able to explain the problem/project issues and objectives with some mistakes. Be specific on some mistakes. Relate more to thinking skill • With little assistance.		• Unable to explain the problem/project issues or objectives. • With assistance. what's the difference with this and the next one? Are you saying you're not assisting the next one?		• Unable to explain the problem/project issues and objectives.	
Applying Basic Knowledge	• Able to explain and relate the basic knowledge to current problem/project correctly. • applying different Level of knowledge to the problem should be emphasized	• Able to explain and relate the basic knowledge to current problem/project with some mistakes.		• Able to explain the basic knowledge. • But incapable to relate to current problem/project.		• Unable to explain the basic knowledge and relate it to current problem/project.	
Information Searching	• Able to identify and gather relevant information from multiple sources (documents, internet and individuals). What's important is to identify the relevant information and not the quantity of sources	• Able to identify and gather relevant information but from few sources (documents/internet/ individuals).		• Able to identify and gather but not relevant information.		• Unable to identify and gather information from any sources.	
Interpretation of Information	• Able to thoroughly interpret the information obtained and relate to current problem/project correctly.	• Able to interpret the information obtained and relate to current problem/project with some mistakes.		• Able to interpret the information obtained. • But incapable to relates to current problem/project		• Unable to interpret the information obtained and relates to current problem/project.	

APPENDIX H

COMMUNICATION AND FULFILLMENT OF TASK					
Communication and fulfillment of task	• Interact with other group members and listen respectfully to other's opinion. • **Successfully fulfill** the responsibility delegated and **done all** the task given.	• Interact with other group members and listen to other's opinion. • **Fulfill** the responsibility delegated but some tasks are **not successfully done.**	• Interact with other group members **but mostly dominate the discussion** and **always oppose** other's opinion. • **Fulfill** the responsibility delegated but **most tasks are not successfully done.**	• **Did not/less** interact with other group members and did **not/less listen** to other's opinion. • **Unable to fulfill** the responsibility delegated to the task given.	
TOTAL WEEK ONE MARKS:					

Signature: ______________________ Name: ______________________________ Date: ______________________

Example of Problem solving Process Rubrics (PPR) Ver. 2 (Week 1)

PROBLEM-SOLVING PROCESS RUBRICS
(WEEK 1)

Laboratory/Project Title:______________________________________Program/Section No. /Group. No.:_____________ Name: __________________________________

INSTRUCTION TO LAB'S FACILITATOR: Please WRITE the scores that you choose to complete this assessment form.

Criteria	Levels				Scores
	Exemplary 5	Proficient 4 3	Developing 2 1	Need Improvement 0	
PROBLEM IDENTIFICATION					
Defining the Problem/ Project	• **Able** to explain the problem/project issues and objectives correctly and **clearly.** • **With no assistance.**	• **Able** to explain the problem/project issues and objectives **with some mistakes.** • **With little assistance.**	• **Unable** to explain the problem/project issues **or** objectives. • **With assistance.**	• **Unable** to explain the problem/project issues **and** objectives. • **Without are great deal of assistance.**	
Applying Basic Knowledge	**Able** to explain and relate the basic knowledge to current problem/project **correctly.**	• **Able** to explain and relate the basic knowledge to current problem/project **with some mistakes.**	• **Able** to explain the basic knowledge. • **But incapable** to relate to current problem/project.	• **Unable** to explain the basic knowledge **and** relate it to current problem/project.	
Information Searching	• **Able** to identify and gather **relevant** information from **multiple** sources (documents, internet and individuals).	• **Able** to identify and gather **relevant** information but from **few sources** (documents/internet/individuals).	• **Able** to identify and gather but **not relevant** information.	• **Unable** to identify and gather information from any sources.	
Interpretation of Information	• **Able** to **thoroughly interpret** the information obtained and **relate** to current problem/project **correctly.**	• **Able** to **interpret** the information obtained and **relate** to current problem/project **with some mistakes.**	• **Able** to **interpret** the information obtained. • **But incapable to relates** to current problem/project	• **Unable** to interpret the information obtained and relates to current problem/project.	

COMMUNICATION AND FULFILLMENT OF TASK					
Communication and fulfillment of task	• Interact with other group members and listen respectfully to other's opinion. • **Successfully fulfill** the responsibility delegated and the entire task assigned.	• Interact with other group members and listen to other's opinion. • **Fulfill** the responsibility delegated but some tasks are **not successfully done.**	• Interact with other group members **but mostly dominate the discussion** and **always oppose** other's opinion. • **Fulfill** the responsibility delegated but **most tasks are not successfully done.**	• **Did not/less** interact with other group members and did **not/less listen** to other's opinion. • **Unable to fulfill** the responsibility delegated to the task given.	
				TOTAL WEEK ONE MARKS:	

Signature: ______________________________ Name: ____ Date: ___________________________

Example of Problem solving Process Rubrics (PPR) Ver. 3 (Week 1)

PROBLEM-SOLVING PROCESS RUBRICS
(WEEK 1)

Laboratory/Project Title:__________________________________Program/Section No. /Group. No.:____________ Name: ______________________________

INSTRUCTION TO LAB'S FACILITATOR: Please WRITE the scores that you choose to complete this assessment form.

Criteria	Levels						Scores
	Exemplary	Proficient		Developing		Need Improvement	
	6	5	4	3	2	1	
PROBLEM IDENTIFICATION							
Defining the Problem/ Project	• Clearly identify and explain the problem/project issues correctly. • Define the main objectives of the problem/project correctly. • With no assistance.	• Identify and explain the problem/project issues with some mistakes. • Define the main objectives of the problem/project with some mistakes. • With little assistance.		• Able to identify and explain the problem/project issues with few mistakes. • Unable to define the main objectives of the problem/project. • With assistance.		• Unable to identify the problem/project issues and objectives.	
Applying Previous Knowledge	• Able to explain and relate the previous knowledge to current problem/project correctly.	• Able to explain and relate the previous knowledge to current problem/project with some mistakes.		• Able to explain the previous knowledge. • Unable to relate to current problem/project.		• Unable to explain the previous knowledge and relate it to current problem/project.	
Searching and Interpreting Information	• Able to identify relevant information to solve problem/project. • Able to thoroughly interpret the information obtained and relate to current problem/project correctly.	• Able to identify relevant information to solve problem/project. • Able to interpret the information obtained and relate to current problem/project but with some mistakes.		• Able to identify information but not relevant to solve problem/project. • Able to interpret the information obtained but unable to relate to current problem/project.		• Unable to identify information to solve the problem/project. • Unable to interpret the information obtained and relates to current problem/project.	

APPENDIX J

COMMUNICATION IN GROUP WORK					
Communication in group work	• Actively participate in group work and listen to other's opinion. • Actively respond in giving ideas and answer the questions related to the problem/project correctly.	• Participate in group work and listen to other's opinion. • Respond in giving ideas and answer the questions related to the problem/project but with some mistake.	• Participate in group work but mostly dominate the discussion and always oppose other's opinion. • Less respond in giving ideas and answer the questions related to the problem/project.	• Did not participate in group work and listen to other's opinion. • Did not respond in giving ideas and answer the questions related to the problem/project with some mistake.	
FULFILLMENT OF TASK					
Fulfillment of Task	• Successfully fulfill the responsibility delegated and the entire task assigned.	• Fulfill the responsibility delegated but some tasks are not successfully done.	• Fulfill the responsibility delegated but most tasks are not successfully done.	• Unable to fulfill the responsibility delegated to the task given.	
				TOTAL WEEK ONE MARKS:	

Signature: ______________________________ Name: ____ Date: ___________________________

Example of Problem solving Process Rubrics (PPR) Ver. 4 (Week 1)

PROBLEM-SOLVING PROCESS RUBRICS
(WEEK 1)

Laboratory/Project Title:____ Program/Section No. /Group. No.:______________ Name: ____________________________________

INSTRUCTION TO LAB'S FACILITATOR: Please WRITE the scores that you choose to complete this assessment form.

Criteria	Levels				Scores
	Exemplary	Proficient	Developing	Need Improvement	
	6	5 / 4	3 / 2	1	
PROBLEM IDENTIFICATION					
Defining the Engineering Problem	• **Clearly identify, define** and **explain** the issues and **the main objectives** of engineering problem/project **correctly.** • With **no** assistance.	• **Identify, define** and **explain** the issues and the main **objectives** of engineering problem/project **with some mistakes.** • With **little** assistance.	• **Identify and explain** the issues **but cannot define** the main objectives of engineering problem/project. • **With assistance.**	• **Cannot identify, define** and **explain** the issues and **the main objectives of** engineering problem/project. • With a great deal of assistance.	
Applying Engineering Fundamental Knowledge	• **Clearly explain** and **apply** the engineering fundamental knowledge to solve the problem/project **correctly.**	• **Explain** and **apply** the engineering fundamental knowledge to solve the problem/project with **some mistake.**	• **Explain** the engineering fundamental knowledge **but cannot apply** to solve the problem/project.	• **Cannot explain and apply** the engineering fundamental knowledge to solve the problem/project.	
Identifying and Interpreting Relevant Information	• **Identify** and **thoroughly interpret** the relevant information obtained to **relate** with the problem/project **correctly.**	• **Identify** and **interpret** the relevant information obtained to relate with the problem/project **but with some mistakes.**	• **Identify and interpret** the information obtained **but cannot relate** with the problem/project.	• **Cannot identify** and **interpret** the information obtained to relate with the problem/project.	
COMMUNICATION IN GROUP WORK					
Communication in group work	• **Actively participate, listen** to other's opinion and **respond in giving ideas** and **answer** the questions related to the problem/project **correctly.**	• **Participate, listen** to other's opinion **and respond in giving ideas and answer** the questions related to the problem/project **but with some mistake.**	• **Passively participate, listen** to other's opinion **and less respond in giving ideas and answer the questions** related to the problem/project.	• **Did not participate, listen to other's opinion and did not respond** in giving ideas and answer the questions related to the problem /project with some mistake.	
FULFILLMENT OF TASK					
Fulfillment of Task	• **Successfully fulfill** the responsibility delegated and **the entire task assigned.**	• **Fulfill** the responsibility delegated **but some tasks are not successfully done.**	• **Fulfill** the responsibility delegated **but most tasks are not successfully done.**	• **Did not fulfill** the responsibility delegated to the task given.	
				TOTAL WEEK ONE MARKS:	

APPENDIX L

Bloom Taxonomy Action Verbs

Level	Definition	Sample verbs					Sample behaviors
KNOWLEDGE	Student recalls or recognizes information, ideas, and principles in the approximate form in which they were learned.	arrange define describe duplicate	identify label list match	memorize name order outline	recognize relate recall repeat	reproduce select state	The student will define the 6 levels of Bloom's taxonomy of the cognitive domain.
COMPREHENSION	Student translates, comprehends, or interprets information based on prior learning.	explain summarize paraphrase describe illustrate classify	convert defend describe discuss distinguish estimate explain	express extend generalized give example(s) identify indicate	infer locate paraphrase predict Recognize	rewrite review select summarize translate	The student will explain the purpose of Bloom's taxonomy of the cognitive domain.
APPLICATION	Student selects, transfers, and uses data and principles to complete a problem or task with a minimum of direction.	use compute solve demonstrate apply construct	apply change choose compute demonstrate discover dramatize	employ illustrate interpret manipulate modify operate	practice predict prepare produce relate schedule	show sketch solve use write	The student will write an instructional objective for each level of Bloom's taxonomy.
ANALYSIS	Student distinguishes, classifies, and relates the assumptions, hypotheses, evidence, or structure of a statement or question	analyze categorize compare contrast separate apply	change discover choose compute demonstrate dramatize	employ illustrate interpret manipulate modify operate	practice predict prepare produce relate schedule	show sketch solve use write	The student will compare and contrast the cognitive and affective domains.
SYNTHESIS	Student originates, integrates, and combines ideas into a product, plan or proposal that is new to him or her.	create design hypothesize invent develop arrange assemble	categorize collect combine comply compose construct create	design develop devise explain formulate generate plan	prepare rearrange reconstruct relate reorganize revise	rewrite set up summarize synthesize tell write	The student will design a classification scheme for writing educational objectives that combines the cognitive, affective, and psychomotor domains.
EVALUATION	Student appraises, assesses, or critiques on a basis of specific standards and criteria.	Judge Recommend Critique Justify Appraise Argue	Assess Attach Choose Compare Conclude Contrast	Defend Describe Discriminate Estimate Evaluate Explain	Judge Justify Interpret Relate Predict	Rate Select Summarize Support Value	The student will judge the effective-ness of writing objectives using Bloom's taxonomy.

Reference: http://chiron.valdosta.edu/whuitt/col/cogsys/bloom.html

APPENDIX M

Validation Form (Expert A)

LECTURER DETAILS

Name: Sharifah Kamilah bt. Syed Yusof

Position: Assoc. Prof.

Faculty/Department: Faculty of Electrical Engineering

Teaching experiences: 22 years. years

PBLab Teaching experiences: Since 2007 years

CONTENT VALIDATION

Please choose only one by ticking (√) at the given column.

- [x] I hereby certify and agree that this rubrics have been designed well and it can be used for this research.
- [ ] I hereby not certify and not agree that this rubrics have been designed well and it can't be used for this research.

Comments /Recommendations:

—

SIGNATURES

Lecturer Signature: [signature] Date: 30/9/2014

ASSOC. PROF. DR. SHARIFAH KAMILAH BT SYED YUSOF
Manager
(Academic Audit, Accreditation and Recognition)
Centre for Quality and Risk Management
Universiti Teknologi Malaysia
81310 Johor Bahru

Validation Form (Expert B)

APPENDIX N

INSTRUMENT VALIDATION FORM

LECTURER DETAILS

Name: NORHAFIZAH RAMLI

Position: SENIOR LECTURER.

Faculty/Department: FKE / ECED

Teaching Experiences: 20+ YEARS. years

PBLab Teaching Experiences : SINCE 2007 years

CONTENT VALIDATION

Please choose only one by ticking (√) at the given column.

- [x] I hereby certify and agree that this instrument have been well designed and it can be used for this research.
- [ ] I hereby certify that not agree that this instrument have been well designed and it can't be used for this research.

Comments / Recommendations:

MOST RUBRICS ARE RECOMMENDABLE WITH ONLY MINOR CORRECTION TO IMPROVE READABILITY AND EASE OF ASSESSING BY LECTURERS.

SIGNATURES

Lecturer Signature: Date: 30/9/2014

NORHAFIZAH RAMLI
Senior Lecturer
FACULTY OF ELECTRICAL ENGINEERING
UNIVERSITI TEKNOLOGI MALAYSIA
81310 UTM JOHOR BAHRU.

Validation Form (Expert C)

INSTRUMENT VALIDATION FORM

LECTURER DETAILS

Name: Dr. Rohaya Talib

Position: Senior Lecturer

Faculty/Department: Education (Measurement & Evaluation)

Teaching Experiences: 22 years

PBLab Teaching Experiences : — years

CONTENT VALIDATION

Please choose only one by ticking (√) at the given column.

- [√] I hereby certify and agree that this instrument have been well designed and it can be used for this research.
- [ ] I hereby certify that not agree that this instrument have been well designed and it can't be used for this research.

Comments /Recommendations:

The rubric has been developed according to the recommended procedures (conceptual definition, operational definition & validation). Suggestion to develop the manual..

SIGNATURES

Lecturer Signature: [signature] Date: 12/10/2014

DR. ROHAYA TALIB
Senior Lecturer
Department of Educational Foundation
Faculty of Education
81310 UTM Johor Bahru

APPENDIX O

Final Problem solving Process Rubrics (PPR)

PROBLEM-SOLVING PROCESS RUBRICS
(WEEK 1)

Laboratory/Project Title:____Program/Section No. /Group. No.:____________________ Group members: M1:______________________________________

M2: ____________________________________ M3: _____________________________________ M4:_____________________________________ M5:______________________________________

INSTRUCTION TO LAB'S FACILITATOR: Please <u>WRITE</u> the scores that you choose to complete this assessment form.

CRITERIA	LEVELS				STUDENT'S SCORES				
	Exemplary	Proficient	Developing	Need Improvement					
	6	5 / 4	3 / 2	1	M1	M2	M3	M4	M5
PROBLEM IDENTIFICATION									
Defining the Engineering Problem	• Clearly identify, define and explain the issues and the main objectives of engineering problem/project correctly. • With no assistance.	• Identify, define and explain the issues and the main objectives of engineering problem/project with some mistakes. • With little assistance.	• Identify and explain the issues but cannot define the main objectives of engineering problem/project. • With assistance.	• Cannot identify, define and explain the issues and the main objectives of engineering problem/project. • With a great deal of assistance.					
Applying Engineering Fundamental Knowledge	• Clearly explain and apply the engineering fundamental knowledge to solve the problem/project correctly.	• Explain and apply the engineering fundamental knowledge to solve the problem/project with some mistake.	• Explain the engineering fundamental knowledge but cannot apply to solve the problem/project.	• Cannot explain and apply the engineering fundamental knowledge to solve the problem/project.					
Identifying and Interpreting Relevant Information	• Identify and thoroughly interpret the relevant information obtained to relate with the problem/project correctly.	• Identify and interpret the relevant information obtained to relate with the problem/project but with some mistakes.	• Identify and interpret the information obtained but cannot relate with the problem/project.	• Cannot identify and interpret the information obtained to relate with the problem/project.					
COMMUNICATION IN GROUP WORK									
Communication in group work	• Actively participate, listen to other's opinion and respond in giving ideas and answer the questions related to the problem/project correctly.	• Participate, listen to other's opinion and respond in giving ideas and answer the questions related to the problem/project but with some mistake.	• Passively participate, listen to other's opinion and less respond in giving ideas and answer the questions related to the problem/project.	• Did not participate, listen to other's opinion and did not respond in giving ideas and answer the questions related to the problem /project with some mistake.					
FULFILLMENT OF TASK									
Fulfillment of Task	• Successfully fulfill the responsibility delegated and the entire task assigned.	• Fulfill the responsibility delegated but some tasks are not successfully done.	• Fulfill the responsibility delegated but most tasks are not successfully done.	• Did not fulfill the responsibility delegated to the task given.					
				TOTAL WEEK ONE MARKS:					

APPENDIX P

PROBLEM-SOLVING PROCESS RUBRICS
(WEEK 2)

Laboratory/Project Title:______________________________________ Program/Section No. /Group. No.:_____________ Name: ______________________________

INSTRUCTION TO LAB'S FACILITATOR: Please <u>WRITE</u> the scores that you choose to complete this assessment form.

Criteria	Levels						Scores
	Exemplary	Proficient		Developing		Need Improvement	
	6	5	4	3	2	1	
PROJECT PLANNING							
Developing the Plan	• **Clearly identify** the steps or frameworks (diagram, written description) and **develop concise plan** to solve the problem. • With **no** assistance.	• **Identify** the steps or frameworks (diagram, written description) and **develop plan** to solve the problem. • With **little** assistance.		• **Identify** the steps or frameworks (diagram, written description) **but some develop plan** is **indirectly** addresses the problem. • **With assistance.**		• **Cannot identify** the steps or frameworks (diagram, written description)and **develop plan** to addresses the problem • With a great deal of assistance.	
Applying Engineering Fundamental Knowledge	• **Clearly explain** and **apply** the engineering fundamental knowledge to solve the problem/project **correctly.**	• **Explain** and apply the engineering fundamental knowledge to solve the problem/project with **some mistake.**		• **Explain** the engineering fundamental knowledge **but cannot apply** to solve the problem/project.		• **Cannot explain and apply** the engineering fundamental knowledge to solve the problem/project.	
Identifying and Interpreting Relevant Information	• **Identify and thoroughly interpret** the relevant information obtained to **relate** with the problem/project **correctly.**	• **Identify and interpret** the relevant information obtained **to relate** with the problem/project **but with some mistakes.**		**Identify and interpret** the information obtained **but cannot relate** with the problem/project.		• **Cannot identify** and **interpret** the information obtained **to relate** with the problem/project.	
IMPLEMENTING ENGINEERING DESIGN							
Hardware and/or Software Tools Usage	• **Identify and create the correct and relevant** equipment connection and/or coding development to address the problem. • Without assistance	• **Identify and create the relevant** equipment connection and/or coding development **but with some mistake** to address the problem. • With little assistance		• **Identify** the equipment and/or coding but cannot **create the connection and development** to address the problem. • With assistance		• **Cannot identify and create** the equipment connection and/or coding development to address the problem. • With a great deal of assistance.	
Implementing Engineering Design	• **Design and explain** the hardware and/or software development **that meet** the specified specification in order to solve the problem/project. • Without assistance.	• **Design** and **explain** the hardware and/or software development **that meet** the specified specification **but with some mistake** in order to solve the problem/project. • With little assistance.		• **Design but cannot explain** the hardware and/or software development **that meet the** specified specification in order to solve the problem/project. • With assistance		• **Cannot design** and **explain** the hardware and/or software development that meet the specified specification in order to solve the problem/project. • With a great deal of assistance.	
COMMUNICATION IN GROUP WORK							

Communication in group work	• **Actively participate, listen** to other's opinion and **respond in giving ideas and answer** the questions related to the problem/project **correctly.**	• **Participate, listen** to other's opinion and **respond in giving ideas and answer** the questions related to the problem/project **but with some mistake.**	• **Passively participate, listen** to other's opinion and **less respond in giving ideas and answer the questions** related to the problem/project.	• **Did not participate, listen to other's opinion** and **did not respond** in giving ideas and answer the questions related to the problem /project with some mistake.	
FULFILLMENT OF TASK					
Fulfillment of Task	• **Successfully fulfill** the responsibility delegated and **the entire task assigned**.	• **Fulfill** the responsibility delegated **but some tasks are not successfully done.**	• **Fulfill** the responsibility delegated **but most tasks are not successfully done.**	• **Did not fulfill** the responsibility delegated to the task given.	
				TOTAL WEEK TWO MARKS:	

Signature: ______________________ Name: ______________________________ Date: ____________________

PROBLEM-SOLVING PROCESS RUBRICS
(WEEK 3)

Laboratory/Project Title:____________________________ Program/Section No. /Group. No.:______________ Group members: M1:__________________________

M2: _______________________ M3: _______________________ M4:_______________________ M5:_______________________

INSTRUCTION TO LAB'S FACILITATOR: Please WRITE the scores that you choose to complete this assessment form.

Criteria	Levels				Scores				
	Exemplary	Proficient	Developing	Need Improvement					
	6	5 / 4	3 / 2	1	M1	M2	M3	M4	M5
IMPLEMENTING ENGINEERING DESIGN									
Implementing Engineering Design	• **Design and explain the** hardware and/or software development that meet the specified specification in order to solve the problem/project. • Without assistance.	• **Design** and explain the hardware and/or software development that meet the specified specification but **with some mistake** in order to solve the problem/project. • With little assistance.	• **Design but cannot explain** the hardware and/or software development that meet the specified specification in order to solve the problem/project. • With assistance	• **Cannot design** and explain the hardware and/or software development that meet the specified specification in order to solve the problem/project. • With a great deal of assistance.					
Hardware and/or Software Tools Usage	• **Identify and create the correct and relevant** equipment connection and/or coding development to address the problem. • Without assistance	• **Identify and create the relevant** equipment connection and/or coding development **but with some mistake** to address the problem. • With little assistance	• **Identify** the equipment and/or coding **but cannot create the connection and development** to address the problem. • With assistance	• **Cannot identify and create** the equipment connection and/or coding development to address the problem. • With a great deal of assistance.					
PROJECT ANALYSIS									
Interpretation of results	• **Analyze, critically interpret and conclude** the results related to accepted engineering fundamental theory **correctly.**	• **Analyze,** interpret and **conclude** the results related to accepted engineering fundamental theory but **with some mistakes.**	• **Analyze the results but cannot interpret** and conclude them related to the accepted engineering fundamental theory.	• **Cannot analyze, interpret** and conclude the results related to accepted engineering fundamental theory.					
COMMUNICATION IN GROUP WORK									
Communication in group work	• **Actively participate, listen** to other's opinion and **respond in giving ideas and answer** the questions related to the problem/project **correctly.**	• **Participate,** listen to other's opinion and **respond in giving ideas and answer** the questions related to the problem/project **but with some mistake.**	• **Passively participate, listen** to other's opinion and **less respond in giving ideas and answer the questions** related to the problem/project.	• **Did not participate, listen to other's** opinion **and did not respond** in giving ideas and answer the questions related to the problem /project with some mistake.					
FULFILLMENT OF TASK									
Fulfillment of Task	• **Successfully fulfill** the responsibility delegated and **the entire task assigned.**	• **Fulfill** the responsibility delegated **but some tasks are not successfully done.**	• **Fulfill** the responsibility delegated **but most tasks are not successfully done.**	• **Did not fulfill** the responsibility delegated to the task given.					

PROBLEM-SOLVING PROCESS RUBRICS
(WEEK 4)

Laboratory/Project Title:______________________________ Program/Section No. /Group. No.:________________ Group members: M1:______________________________

M2: ____________________________ M3: ____________________________ M4:____________________________ M5:____________________________

INSTRUCTION TO LAB'S FACILITATOR: Please <u>WRITE</u> the scores that you choose to complete this assessment form.

CRITERIA	LEVELS						STUDENT'S SCORES				
	Exemplary	Proficient		Developing		Need Improvement	M1	M2	M3	M4	M5
	6	5	4	3	2	1					
EVALUATE THE SOLUTIONS											
Evaluate the Solutions	• Correctly solve the problem with relevant solution and achieve the objectives. • Clearly explain and/or demonstrate the process and reason for solution correctly.	• Solve the problem with relevant solution and achieve the objectives. • Explain and/or demonstrate the process and reason for solution but with some mistakes.		• Solve the problem with solution and achieve the objectives. • Cannot explain and/or demonstrate the process and reason for solution.		• Cannot solve the problem with relevant solution and achieve the objectives. • Cannot explain and/or demonstrate the process and reason for solution.					
PROJECT ANALYSIS											
Interpretation of results	• Analyze, critically interpret and conclude the results related to accepted engineering fundamental theory correctly.	• Analyze, interpret and conclude the results related to accepted engineering fundamental theory but with some mistakes.		• Analyze the results but cannot interpret and conclude them related to the accepted engineering fundamental theory.		• Cannot analyze, interpret and conclude the results related to accepted engineering fundamental theory.					
COMMUNICATION IN GROUP WORK											
Communication in group work	• Actively participate, listen to other's opinion and respond in giving ideas and answer the questions related to the problem/project correctly.	• Participate, listen to other's opinion and respond in giving ideas and answer the questions related to the problem/project but with some mistake.		• Passively participate, listen to other's opinion and less respond in giving ideas and answer the questions related to the problem/project.		• Did not participate, listen to other's opinion and did not respond in giving ideas and answer the questions related to the problem /project with some mistake.					
FULFILLMENT OF TASK											
Fulfillment of Task	• Successfully fulfill the responsibility delegated and the entire task assigned.	• Fulfill the responsibility delegated but some tasks are not successfully done.		• Fulfill the responsibility delegated but most tasks are not successfully done.		• Did not fulfill the responsibility delegated to the task given.					

Problem solving Process Rubrics (PPR) Manual Guide

PBLab Problem-solving Process Rubrics User Guide

A. Problem-solving Process Rubrics Structure

1) This is an **individual** rubrics assessment.
2) This rubric was designed for assessing **student's problem-solving process** during the PBLab session.
3) There are **4 different rubrics** (determined by week) for assessing student's problem-solving process in this PBLab course.
4) This rubrics consists 3 main parts which are :
   a. **Criteria**:
      - Each rubric has its own criteria determined by specified problem solving process occurred during PBLab session from week one until week four.
   b. **Descriptors** :
      - The descriptors for each problem-solving process criteria represent the performance expectations of students during PBLab session from week one until week four. The details of the descriptors serve as means to help facilitators to distinguish student's performances in a more precise and consistent manners.
   c. **Levels:**
      - There are 4 levels of student's performances developed in this rubrics design where the highest performance is Exemplary (rated as 6) followed by Proficient (rated between 5 to 4), Developing (rated between 3 to 2) and the lowest is Need Improvement (rated as 1).
      - The ratings for the Proficient level are set to be in the range of 5 to 4 while for Developing level is between ranges 3 to 2. This range is in order to help the facilitators to differentiate the student's performances more effectively and less bias.

B. How to use Problem-solving Process Rubrics?

1) At the first week of PBLab session, explain to your students the rubrics criteria and what they will be assessed from week one until week four.
2) Please make sure that you use the right rubrics at the right PBLab week. Each week has its own rubrics assessments (eg. Rubrics for week three is evaluated during week three of PBLab session.)
3) There are 6 ratings (between 6 to 1) for each rubrics. Please choose only one rating for each criteria which clearly represent your student's performances.
4) Each rubric must be marked and the complete rubrics must be submitted to the lab assistant at the end of PBLab session of week one until week four.
5) The marks obtained from each problem solved at the respective laboratory are then averaged to obtain the final grade for each student.
6) This evaluation process is repeated when the group of students moves to the other laboratories in the fifth and ninth week of the semester.

Problem solving Process Rubrics (PPR) Facilitators Guide

30/9/2014

RUBRICS FACILITATORS GUIDE

No.	Criteria / Definitions	Facilitator is encourage to:
1.	**Defining the Engineering Problem** Ability to identify and explain the issues and objectives of the problem/project.	i. Observe the students during their discussion session. Identify who actively and passively participate in the group. ii. Ask the students during the discussions session regarding the problem/project. Eg. "What are the issues here?", "What are the main objectives?" .Identify whose answers the questions.
2.	**Applying Engineering Fundamental Knowledge** Ability to identify and apply the previous fundamental knowledge to solve the problem/project.	i. Ask the students during the discussions session regarding the previous fundamental knowledge that they had learn. Eg. "What you have learned before and how to relate it with this problem/project?". Identify whose answers the questions.
3.	**Identifying and Interpreting Relevant Information** Ability to identify, interpret and relate the information obtained to solve the problem/project.	i. Observe the students during their discussion time. Identify who actively and passively participate in the group. ii. Ask the students during the discussions session regarding the information obtained. Eg. "What are the information that you get?", "How the information relate with the problem?". Identify whose answers the questions.
4.	**Developing the Plan** Ability to develop the plan and identify the suitable framework or steps in to solve the problem/project.	i. Ask the students to explain their plan by drawing or showing their steps or framework in writing description or diagram. Identify who actively answers the questions.
5.	**Hardware and/or Software Tools Usage** Ability to identify and create the equipment connection and coding development to solve the problem/project.	i. Observe the students during lab session and identify who actively and passively participate in connecting the equipment or developing the coding.
6.	**Implementing Engineering Design** Ability to design the solution that meets the given specification.	i. Observe the students during lab session and identify who actively and passively participate in connecting the equipment or developing the coding. ii. Ask the students to explain the equipment connection or the coding. Determine whose answers the questions.
7.	**Interpretation of results** Ability to analyse and interpret the results obtained.	i. Ask the students to conclude the results obtained. Determine who's actively and passively giving ideas and answers the questions.
8.	**Evaluate the Solutions** Ability to explain and demonstrate the process and reason for solution.	i. Check the student's solutions and ask the students to explain and/or demonstrate the process until reach the solutions. Determine who's actively and passively giving ideas and answers the questions.
9.	**Communication in Group Work** Ability to interact within group members.	i. Observe the students during lab session and identify who actively and passively participate in the group.
10	**Fulfillment of Task** Ability to fulfill the task given.	i. Ask the students at the end of the lab session. Eg. "How you divide the task?" , "What is your task for today?".

APPENDIX R

APPENDIX S

List of Publications

1) Azli, N.A., Shamsulbahri, N.A. & Abu, N.S. & Ramli, N. (2012). Outcome-based Sciences, Technology, Engineering and Mathematics Education: Innovative Practices: A Project-based laboratory (PBLab) Model for an Electrical Engineering Program, *IGI Global Publisher*, 107-123.

2) Shamsulbahri N.A., Azli, N.A. & Samah N.A. (2011). Assessing Electrical Engineering Students' Generic Skills Acquirement through Project-based laboratory, Education Postgraduate Research Seminar (EDUPRESS) ,UTM, 29-40.

3) Shamsulbahri N.A., Azli N.A. & Samah N.A. (2012). Problem-based Learning Laboratory (PBLab): Facilitators' Perspective on Rubric Assessment. *Regional Conferences Engineering Engineering. Negeri Sembilan.*

4) Shamsul Bahri, N.A. & Azli, N.A. (2012). Analysis on Learning Outcomes Achievement in a Project-based laboratory (PBLab) Course, *4^{th} International Congress on Engineering Education (ICEED 2012)* , Penang, Malaysia. 53-57.

5) Shamsul Bahri, N.A. & Azli, N.A. (2014). An Exploratory study: Problem solving Process in a Project-based laboratory (PBLab) Course, *International Conferences on Learning and Teaching in Computer and Engineering, (LATICE 2014), Sarawak, Malaysia*.

6) Shamsul Bahri, N.A., Azli, N.A. & Samah, N.A. (2013). From Conventional to Non-conventional laboratory: Electrical Engineering Student Perception, *4^{th} International Research Symposium on Problem-based Learning (IRSPBL), Putrajaya, Malaysia.*

7) Shamsul Bahri, N.A., Azli, N.A. & Samah, N.A. (2016). Determining the Elements of Problem solving Strategies in Project-based Laboratory Course, *International Journal of Engineering Education (IJEE),* 32(1B), 409-423.