A theoretical model for the effectiveness of project-based learning in engineering design education

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A THEORETICAL MODEL FOR THE EFFECTIVENESS OF PROJECT-BASED LEARNING IN ENGINEERING DESIGN EDUCATION

by

Mingyi Gao

A Doctoral Thesis submitted in partial fulfillment of the requirements for the award of Ph D of Loughborough University

March, 2012

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Abstract

The main focus of this thesis is on the effectiveness of project-based learning (PBL) in engineering design. The literature review has shown that there is much confusion and ongoing arguments concerning the implementation of PBL in engineering design, and there lacks consensus on its effectiveness. Little research has been done on providing measurable metrics of PBL effectiveness, not to mention discovering the optimal PBL and its underlying mechanisms based on solid educational theories and rigorous research methodology.

In this thesis, the measurement of the optimal PBL effectiveness (effect) is studied and a theoretical model of PBL is built in order to identify parameters (cause) controlling the effectiveness and to study the interplay between effectiveness and the parameters. The model is built through three main phases, with a combination of qualitative and quantitative research methods.

In phase one, the effectiveness of PBL is studied from the perspectives of the engineering design lecturers and engineering graduates by interviews, which is used to represent effect (Y axis) of the model.

In phase two, on the basis of self-directed learning theory (SDL) and learner engagement theory, two key parameters of PBL, i.e. SDL and learner engagement, are identified and quantified respectively to represent cause (X axis) of the model. With the key parameters of PBL (X axis) and PBL effectiveness (Y axis) obtained, a theoretical model of PBL is proposed. The model is verified by means of experiments (student self-reported surveys). A specified Moving Average Method (MAM) is used for data analysis and findings demonstrate different trends of the relations between SDL and PBL effectiveness, and between learner engagement and PBL effectiveness.

Consequently, a 3D model of PBL is built by combining the data in aforementioned 2D models, through which the optimal PBL effectiveness in 3D are identified and measured and the
interplay between different parameters are found.

In phase three, in order to find out more delicate features in PBL ignored by MAM, the dynamic interaction of individual differences in PBL teamwork is explored by the ethnological method (including participant observations and interviews), which is conducted as a supplement to the model of PBL.

The theoretical model of PBL effectiveness proposed in this thesis is novel and groundbreaking. Firstly, a series of 2D and 3D models are presented and the relations between SDL, learner engagement and PBL effectiveness are revealed for the first time, which provides guidance for the optimal PBL measurement and implementation. Secondly, a qualitatively-quantitatively-combined strategy is used to discover the mechanisms controlling optimal PBL at different scales. Thirdly, the experiments verifying the model provide fresh quantitative insight into optimal PBL. In summary, the research in this thesis opens up a new research methodology for studying PBL effectiveness, which makes contribution to the educational field as well.

Keywords: Project-based learning, Self-directed learning, Learner engagement, Optimal PBL effectiveness, 3D model, Individual differences, Engineering design, Pedagogy.
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Chapter 1.

INTRODUCTION OF THE THESIS

1.1 FIELD OF THIS RESEARCH

This dissertation presents pedagogical research on the effectiveness of using project-based learning in engineering design education. The term ‘pedagogical research’ here refers to both the teaching and learning irrespective of the student’s age (Yorke, 2000).

There is a long trend that pedagogical research in higher education, both in the UK and worldwide, is undervalued in comparison with other research. In the UK, the research assessment exercises Research Assessment Exercises [RAEs] particularly played a negative role in the development of pedagogical research. However, pedagogical research in higher education is “clearly intended to be useful” in that “it is critical to the development of effective and efficient practice in higher education” (Yorke, 2000).

On the other hand, higher education itself in the UK (and worldwide as well) underwent some significant changes in recent decades. Firstly, there is an increasing amount of students participating in higher education. This makes the UK’s traditional elitist approach no longer sufficient, and it calls for new teaching and learning approaches to fit today’s mass system in higher education; Secondly, graduates from higher education are facing a wider range of roles in society, thus the higher education “is expected to facilitate the development of a wider range of achievement than ever before” (Knight and Yorke, 2003, p13). Pedagogy, therefore, has become “more sophisticated and wide-ranging”, hence pedagogical research becomes more important (Yorke, 2000).

This research was conducted against the above described background. The focus of this research is the effectiveness of project-based learning in engineering design education.

Project-based learning, as one of the constructivist teaching and learning approaches, is

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increasingly adopted in various subjects in higher education. At the same time, this relatively new approach is also confronted by the continuous arguments about its effectiveness. In the area of engineering education, however, there has been a long history of using project work to integrate disciplines and motivate students (Heitmann, 1996; Heywood, 2005). This is particularly the case in engineering design, which is generally regarded to be the core activity in engineering, and which is usually taught and learnt in the form of doing engineering design projects, either individually or in groups (Dym et al., 2005). The group design project shares much in common with project-based learning (Nelson, 2003). Therefore, in this research, group design project is used as the vehicle to study the effectiveness of project-based learning in engineering education.

In summary, the research field in this research is shown in Figure 1.1:

![Figure 1.1. The research field in this thesis.]

1.2 PURPOSE AND JUSTIFICATION OF THIS RESEARCH
The purpose of this research is to improve the effective implementation of project-based learning by providing some useful guidance for project-based learning practitioners, with specific reference to the teaching and learning in the engineering design project context.

Project-based learning is a relatively new pedagogical approach compared with the traditional, lecture-based teaching approach. Although there is a history as long as 300 years of using projects in professional education, it was originally confined to architectural studies and technical colleges (Heitmann, 1996). It was about 1920s that project method was first brought into general and vocational education on a wide scale, as part of the progressive education

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during the progressive movement in the US (Heitmann, 1996; Morgan, 1984). From its inception, however, project method, like the progressive education as a whole, elicited sharp criticism, and after experiencing a period of flourishing time, collapsed by the late 1950s.

In recent decades, with the development of cognitive psychology, the deeper understanding of student learning, and the new development of educational technology tools, people are taking a new look at project-based learning (Blumenfeld et al., 1991; Morgan, 1980), and at roughly the same time, other similar constructivist teaching and learning approaches are also advocated, including problem-based learning, experiential learning, work-based learning, action learning, service learning, enquiry-based learning, active learning, collaborative/cooperative learning, small group learning, activity-based/led learning, task-based learning, etc. These new pedagogical approaches are increasingly adopted and applied in different subjects in both schools and higher education (Barrows and Tamblyn, 1980; Blumenfeld et al., 1991; Boud and Feletti, 1999; Brown, 2004; Helle et al., 2006; Johnson et al., 1998; Kolb, 1984, 2000; Morgan, 1984; Schmidt and Moust, 2000; Smith and O’Neil, 2003). The same trend can also be found in engineering education (de Graaf and Kolmos, 2003; Dym et al., 2005; Heitmann, 1996, 2005; Kolmas, 1996; Prince and Felder, 2006).

In the UK, efforts were also made on the development of the new pedagogical approaches in both engineering education and other subject fields, such as the project-based learning in Engineering project which involves four institutions including University of Nottingham, Loughborough University, Nottingham Trent University and DeMontfort University, problem-based learning and enquiry-based learning in the University of Manchester, activity-led learning in Coventry University, CDIO project across many UK universities, etc.

As in the past, along with their implementation, the effectiveness issue of these new pedagogical approaches was under severe argument. In higher education, the argument was mainly centred on the comparison between the effectiveness of the new pedagogical approaches, mostly problem-based learning, and the traditional, lecture-based approach. To date, conflicting findings have been reported in student academic achievement/knowledge acquisition, and
positive findings in student satisfaction and skill development (Albanese and Mitchell, 1993; Colliver, 2000; Dochy et al., 2003; Newman, 2004; Kirschner et al., 2006; Norman and Schmidt, 2000; Strobel and van Barveld, 2009; Vermon and Blake, 1993).

Along with the findings reported from these studies, problems within the research process itself have also been noticed and discussed. The major problems include:

1) Difficulty to define precisely what is being studied.

Under the umbrella of constructivism, the different new pedagogical approaches have as many differences as similarities. For example, experiential learning is believed to bear a resemblance to the original model of project-based learning (Helle et al., 2006); project-based learning overlap with work based learning and service learning provided that the learning involves project studies (Helle et al., 2006); project-based learning and problem-based learning, as well as quite many other new pedagogical approaches, involve collaborative and/or cooperative learning (Helle et al., 2006; Prince, 2004; Prince and Felder, 2006); problem-based learning, which shares the same abbreviation as with project-based learning - PBL - in most circumstances, covers various ways of implementation in practice, ranging from the “pure form”, which embraces the problem-centred approach without traditional lectures, to “hybrid form” with different degrees of projects, formal tuition and traditional lectures (Macdonald, 2001; Savin-Baden, 2000). In engineering education, the distinction between project-based learning and problem-based learning is sometimes quite blurred, especially in pedagogical practice (Kolmas, 1996; Kolmos et al., 2009; Prince and Felder, 2006).

On the other hand, as an educational activity, project-based learning can be conceptualized on a number of dimensions and is also implemented in various ways, which makes it difficult to define precisely (Morgan, 1984).

Thus, the overlapping between project-based learning and the new pedagogical approaches and the different ways of implementing project-based learning made it hard to define and interpret precisely what is being studied in the research on their effectiveness.

*Introduction of the Thesis*
2) Multiple and/or conflicting effects of variables on (multiple) learning outcomes

Learning is a complex process which involves very many controllable and uncontrollable variables. The effects of these variables in the learning process are multiple, and sometimes even conflicting with each other. Take the self-directed teamwork for example. There might be the positive effect of teamwork whereas at the same time the negative effect of self-directed learning on student academic achievements in the context of problem-based learning (Norman and Schmidt, 2000; Schmidt and Moust, 2000). Since different implementations of the new pedagogical approaches may emphasize different variables or emphasize the same variables to different extent, the research findings of the overall effectiveness of the new pedagogical approaches are bound to be confusing unless what is being examined has been carefully specified (Prince, 2004). On the other hand, the variables in the learning process may affect more than one learning outcome, thus a broad range of learning outcomes is suggested to be considered (Norman and Schmidt, 2000; Prince, 2004).

3) Flawed research methodology

The lack of methodological and conceptual clarity in the research of the effectiveness of new pedagogical approaches is criticized by many researchers, and some arguments are made on this issue (Mamede et al., 2006; Norman, 2006; Prince, 2004; Sanson-Fisher and Lynagh, 2005) To date, the arguments are mainly centred on the strengths of experimental approaches and randomized experimental design (Mamede et al., 2006; Norman, 2006), the use of structural equations to model certain learning phenomena (Norman and Schmidt, 2000), and the limitation of meta-analysis used in research literature so far (Prince, 2004). The lack of qualitative research was also identified as an important issue (Kolmos et al., 2009).

With these problems existing in current research, the effectiveness issue of new pedagogical approaches, including project-based learning, is far from being settled. The conflicting research findings of student achievement, different implementations, multiple effects of variables on learning outcomes and flawed research methodology make the effectiveness issue controversial and complex, which further affects the effective implementation of these new pedagogical approaches in practice.

Introduction of the Thesis
1.3 POINTS OF DEPARTURE

After examining the research findings to date and the related major problems of the effectiveness issue of the new pedagogical approaches, including project-based learning, two aspects emerge as the points of departure in this research:

a) KNOW aspect: project-based learning, as well as other constructivist pedagogical approaches, claims many benefits compared with traditional lecture-based teaching approach; yet so far there is no agreement on its effectiveness;

b) DO aspect: project-based learning overlaps with other constructivist pedagogical approaches, and is implemented in various ways in practice. There is no agreement, and very little research on how to apply project-based learning better, and/or further, best.

These two aspects are closely related. To study the effectiveness of project-based learning, as well as other constructivist approaches, these two aspects need to be considered at the same time; that is, project-based learning practitioners need to know not only WHAT the effectiveness is, but also WHY it is effective and HOW to implement it more effectively.

1.4 AIMS AND OBJECTIVES

With the overlap between project-based learning and other new pedagogical approaches, differentiating the various ways of project-based learning implementation is the pre-requisite to understanding its effectiveness; further, the ability to understand and measure the effectiveness of project-based learning is the pre-requisite to implementing project-based learning in an optimal way.

To date, there is little research on

1) differentiating the various ways of project-based learning implementation, with the overlapping of project-based learning with other new pedagogical approach taken into consideration;
2) providing metrics for the effectiveness of the different ways of project-based learning implementation.

This research aims to address these issues, aiming to find out relatively effective procedures of project-based learning implementation and to propose measurable metrics for its effectiveness in a particular implementation and the way(s) of further improvement for education practitioners.

This research is to answer the following three research questions:

1. How can the different ways of project-based learning implementation be differentiated?
2. How and to what extent can project-based learning implementation be made more effective?
3. What are measurable metrics for the effectiveness of project-based learning?

In engineering education, design project is widely regarded as the core activity of engineering, and meanwhile, it represents an activity that easily lends itself to the problem oriented approach because of their applied nature (Royal Academy of Engineering, 2005). In this research, design project is taken as the vehicle of project-based learning approach, and the study of the effectiveness of project-based learning is conducted in an engineering design project context.

1.5 A BRIEF OVERVIEW OF THE RESEARCH METHODOLOGIES IN THIS RESEARCH

This research combines quantitative and qualitative research methods, including theoretical model building, interviews, participant observation and surveys. These methods are applied in three aspects:

Firstly, the study of what PBL effectiveness is. Interviews were conducted with design project module teachers and engineering graduates respectively to find out PBL effectiveness categories from their perspectives. All the interviews were audio recorded, and thematic analysis was applied in the data analysis. The categories of PBL effectiveness identified were used in the model of PBL effectiveness built in the subsequent second aspect.
Secondly, the investigation into how better, even the best PBL effectiveness can be achieved and measured. Theoretical models of PBL effectiveness were proposed after two key quantifiable parameters, self-directed learning and learner engagement, were determined based on self-directed learning theory and learner engagement theory. Questionnaires were designed on the basis of the theoretical model, and surveys were conducted to verify the model. The method of moving average was mainly applied to analyze the data.

Thirdly, the exploration of how the individual differences in PBL teamwork interact dynamically. Participant observation at the teamwork and team tutorial was made throughout the design project module, and interviews were made by the end of the module. All the interaction and interview were audio recorded and transcript. Thematic analysis was applied in the data analysis. The study in this aspect is a necessary supplement to the model of PBL effectiveness.

In this way, the quantitative and qualitative methods were combined as a whole in this research.

1.6 OVERVIEW OF THE THESIS CHAPTERS AND STRUCTURE

This thesis is structured into nine chapters. The first three chapters pave the way to the subsequent work. The first chapter provides a general overview of the project; Chapter 2 presents the literature review of project-based learning, engineering education and engineering design; chapter 3 reviews the research methodology in theory and practice, which justifies the methodology used in this research. Chapter 4 shows the study of PBL effectiveness from the perspectives of design project lecturers and engineering graduates, which is also an integrated part in the model building in the subsequent chapters. Chapter 5, 6 and 7 focuses on the theoretical building of the model of PBL effectiveness and its verification. Chapter 8 acts as a supplement to the model by investigating the dynamic interaction of individual differences. Chapter 9 summarizes the findings and provides future recommendations.

1.7 THE PH D PROJECT OUTCOMES

The main outcomes of the project are:

- A novel model of PBL effectiveness has been developed based on educational theories.
Self-directed learning and learner engagement are used as the key characterization parameter of PBL for the first time in achieving and measuring PBL effectiveness;

✧ SDL time is found to be a key parameter of PBL effectiveness. No matter how much learner engagement is made, there always exists an optimal amount of SDL time which is correlated with the optimal PBL effectiveness;

✧ The optimal amount of SDL time varies in different academic years. So is the optimal amount of team-based SDL time. The optimal private SDL time remain similar across academic years;

✧ In year 1 and year 3 and 4, the same optimal amount of SDL time is correlated with both the optimal design ability improvement and optimal transferable skill improvement. In year 2, the optimal SDL time is likely to lead to conflicting design and transferable skill improvement;

✧ Learner engagement generally has positive correlation with PBL effectiveness. The categorized learner engagement, namely, behavioral learner engagement, affective learner engagement and cognitive learner engagement has different extent of influence on PBL effectiveness in different academic years, with the affective learner engagement showing more influence than the other two;

✧ The dynamic interaction of individual differences constitutes a necessary and useful supplement to the model of PBL effectiveness.

1.8 CONCLUSIONS

This chapter provided a general overview of the thesis. The field of this research is introduced first; then the research gap is discussed as the justification of this research, followed by the point of departure of this research which is taken as the principle of settling the problems identified. Concrete aims and objectives are stated and the combination of quantitative and qualitative research methods is introduced. A brief overview of the content of thesis chapters and their structure is presented, which involves two chapters of reviews and four chapters of model building and supplementing. Finally the main outcomes of the research project are listed.
Chapter 2.

LITERATURE REVIEW

The literature review in this chapter was focused on three areas: project-based learning, engineering education and engineering design. A thorough understanding of PBL is the precondition of investigating its effectiveness. The knowledge of engineering education and the role of engineering design in it will provide inevitable context for the study of PBL effectiveness.

2.1 PROJECT-BASED LEARNING

2.1.1 Definition of Project-based learning

Project-based learning was termed as project method early in its time (Adderley, 1975; Kilpatrick, 1921; Kuethe, 1968). The term project-based learning occurred roughly from 1980s (Morgan, 1983, 1984). In some circumstances, projects and project work are also used to refer to project-based learning (Heywood, 2005).

Literally, the term projects or project work are actually quite broad. They may refer to an exercise, a task, a scheme, a programme or an activity; they may be undertaken by individuals or in groups, and carried out in various places, such as laboratory, library, studio, working places or community; they may be of different lengths, from weeks to semesters; and they may have different outcomes, such as written, oral or hands-on work (Brown, 1997).

These varieties may have conflicting educational aims and learning assumptions (Morgan, 1984). Therefore, it is not surprising to find that in higher education a majority of courses include some activity described as a project, yet they are implemented in various ways (Adderley, 1975; Morgan, 1984).

Then what is project-based learning?
Broadly speaking, project-based learning can be used to include “a wide range of learning experiences from small project-options or exercises to a project orientation which may form the basis of an entire university education” (Morgan, 1984, p221). Heitmann distinguishes project-based learning from project-oriented studies, which refers to the use of small projects within individual courses, and project-organized curriculum, which refers to the use of projects as the structuring principle of the entire curriculum (Heitmann, 1996). Hence, in the broad sense, project-based learning can not only mean all those “activities designed to solve a particular problem”; but also refer to a curriculum design “in which all the knowledge requirements were covered by carefully chosen projects” (Heywood, 2005, p 229).

Most people, however, tend to define project-based learning from the perspective of teaching and learning at individual course level. Examples can be seen in the following, with the latter two in the engineering context (The examples are listed in chronological order):

*The project method is not really a specific method. Rather, it is a general name for the form of the teaching-learning process that consists of students’ working on some task with relative little direct interaction with the teacher. The specific project may be assigned by the teacher or may result from student initiative.*

(Kueth, 1968, p 132)

--- Comments: This definition emphasizes the relation between the teacher and the students in the teaching and learning process. It stresses project method is a general rather than a specific term, which indicates the potential variety in its application.

1) *Projects* involve the solution of a **problem**; often, though not necessarily, set by the student himself (or herself);

2) They involve initiative by the student or group of students, and necessitate a variety of educational **activities**;

3) They commonly result in an **end product** (eg: thesis, report, design plans, computer programme and model);

4) Work often goes on for a **considerable length of time**;
5) **Teaching staff** are involved in an *advisory*, rather than authoritarian, role at any or all of the stages-initiation, conduct and conclusion.

*(Adderley et al., 1975, p 1)*

--- Comments: This definition defines project-based learning from six aspects: a) form of the learning – *a variety of activities*; b) driver of the learning – *problem*; c) role of students – *student or groups of students’ initiative*; d) role of the teacher - *advisory*; e) learning time - *a considerable length of time*; f) form of learning outcome - *an end product in the form of thesis, report, design plans, computer programme and model*. This definition is thorough, but it looks more like a summary of the features of project-based learning than a general definition.

“At the most general level, project-based learning can be defined as an *activity* which students *develop an understanding* of a topic or issue through some kind of involvement in an actual (or simulated) *real-life problem or issue* and in which they have *some degree of responsibility* for designing their own activities.” ... “Project work is clearly not just a teaching method,..., but rather a curriculum design process that can raise fundamental questions about the structure and transmission of knowledge.

*(Morgan, 1984, p221, 224)*

--- Comments: This definition defines project-based learning mainly from five aspects: a) the form of the teaching and learning – *(pedagogical) activity*; b) learning outcomes – *development of understanding*; c) driver of the activities: *problems*; d) the nature of problem – *real life problem or issue*; and e) the role of students - *some degree of (student) responsibility*. To some extent, this definition is similar to that of problem-based learning in that the learning process, instead of the final product, is emphasized.

“Project-based learning is a *comprehensive approach* to classroom teaching and learning that is designed to engage students in investigation of authentic *problems*. [It requires] a question or problem that serves to organize and drive *activities* and these activities result in a series of artifacts, or products, that culminate in a *final product* that addresses the driving question.”...

“Students can be responsible for the creation of both the question and the activities, as well as the nature of the artifacts”.... Project-based education requires active engagement of

**Literature Review**
students’ effort over an extended period of time.

(Blumenfeld et al., 1991, p 371)

--- Comments: This definition is based on the learning of school students. It defines problem-based learning in four aspects, with two aspects different from those of Morgan’s definition: a) nature of the pedagogy – a comprehensive (pedagogical) approach; b) form of the teaching and learning – activities; c) driver of the activities: problems; d) the nature of problem - authentic problems ; e) form of learning outcomes - a final product.

“Projects are activities designed to solve a particular problem, and they are often a strategy within a curriculum that employs traditional strategies.”

(Heywood, 2005, p 229)

--- Comments: This definition is made in the context of engineering education. In this definition, two aspects are generalized: a) role of the pedagogy– a curriculum strategy; b) form of the teaching and learning – problem solving activities.

Project-based learning begins with an assignment to carry out one or more tasks that lead to the production of a final product- a design, a model, a device or a computer simulation. The culmination of the project is normally a written and/or oral report summarizing the procedure used to produce the product and presenting the outcome.

(Prince and Felder, 2006, p131)

--- Comments: This definition is also made in the context of engineering education. It places more emphasis on the procedures of project-based learning in engineering than its basic nature. It defines project-based learning from two aspects: a) driver of the learning – assignment which develops into tasks; b) form of learning outcomes - a final product in the form of a written and/or oral report. It should be noted here that problem as the learning driver in others’ definitions is replaced by assignment, which makes project-based learning more like the traditional approach, because in this way students’ initiative and responsibility are vague.

The main aspects covered in the above definitions can be seen more clearly in Table 2.1:
Table 2.1. The main aspects covered in different definitions of project-based learning.

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<tbody>
<tr>
<td>Nature of the pedagogy</td>
<td>a general name</td>
<td>a curriculum design process</td>
<td>a comprehensive approach</td>
<td>a curriculum strategy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Form of the learning</td>
<td>a variety of activities</td>
<td>activities</td>
<td>activities</td>
<td>problem solving activities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driver of the learning</td>
<td>some task problems</td>
<td>problems</td>
<td>a question or problem</td>
<td>Problems. assignment which develops into tasks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nature of problem</td>
<td>real life problem</td>
<td></td>
<td>authentic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Role of students</td>
<td>student initiative</td>
<td>student or groups of students’ initiative</td>
<td>some degree of responsibility</td>
<td>responsible for the creation of questions, activities and the nature of artifacts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Role of the teacher</td>
<td>relatively little interaction with teacher</td>
<td>An advisory</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deliverable for assessment</td>
<td>development of understanding</td>
<td></td>
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</table>
From examining some different definitions of project-based learning as listed above, it can be seen clearly that the different definitions cover more or less different aspects of project-based learning. Comparing other definitions with the last two definitions which are in the engineering education context, it can be found that the latter is more general and vague than the former. The long history of using projects in engineering education which resulted in more various types of projects might be the reason for the vagueness of its definition.

In summary, there has not been a universal definition of project-based learning. The differences in its definitions result from the different emphasis on its different features, as well as from the existence of various types of projects. To better understand what project-based learning is, it is necessary to look at these two aspects respectively.

### 2.1.2 Main Features of Project-based learning

As one of the constructivist approaches, project-based learning has some characteristic features which distinguish it from traditional lecture based approach, and, to some extent, from other
constructivist approaches.

2.1.2.1 Problem Orientation

Problem orientation is generally believed to be one of the distinctive features of project-based learning (Blumenfeld et al., 1991; Helle et al., 2006), and the use of problems as the driver of activities is also one decided difference between project-based learning and traditional/conventional activities in which students learn information without a driving question (Blumenfeld et al., 1991). In some definitions listed above, it can be found that tasks replace problems, so it is necessary to differentiate the two terms: tasks and problems.

1) Task and problem

By comparison, the term tasks is more general than problems in that tasks are regarded to be “the basic instructional unit in classrooms” (Blumenfeld et al., 1991). Blumenfeld et al. (1991) classified tasks into low-level tasks and high-level tasks: the former refers to low-level facts and skills, which “afford students few opportunities to represent knowledge in a variety of ways, pose and solve real problems, or use their knowledge to create artifacts”; the latter means “more cognitively complex tasks, which provide opportunities for solving real problems”.

In project-based learning, problems are used to organize and drive activities in that students are placed in realistic, contextualized problem solving environments and investigate and seek solutions to problems. Thus, the problems used in project-based learning should fall into the category of high-level tasks.

In project-based learning, one key principle is that the outcomes of the problems should not be predetermined so that students could be left with sufficient room to develop their own approaches to the problem solutions (Blumenfeld et al., 1991). This principle reflects the nature of the problems encountered by professionals which is often ill-defined and wicked with multiple, non-guaranteed solutions (Helle et al., 2006; Ormerod, 2005; Schraw et al., 1995). Thus, in project-based learning, the problems should be open-ended so that students can take some responsibility for designing their own studies and construct their knowledge in this
process (Blumenfeld et al., 1991; Morgan, 1984).

2) The issue of real/authentic problems

Concerning the issue of real problems in project-based learning, there are also some related arguments. First, benefits in using real problems have been discussed from different perspectives.

Savery and Duffy (1995) emphasized that “problems must be real” from the perspective of student engagement and motivation: “real problems tend to engage learners more” because “there is a large context of familiarity with the problem”, and “students want to know the outcome of the problem”.

Blumenfeld et al. (1991) argued this issue from the perspective of knowledge construction: “learners construct knowledge by solving complex problems in situations in which they use cognitive tools, multiple sources of information and other individuals as resources”. Helle et al. (2006) expressed the similar opinion by holding that “getting students to solve real life problems during their studies, and to reflect in action and on action, presumably promotes the important process of knowledge restructuring for the development of expertise.”

Prince and Felder (2006) analyzed the benefits of real problems from the perspective of knowledge and skill transfer: cognition research showed “the likelihood that knowledge and skills acquired in one course will transfer to real work settings is a function of the similarity of the two environments”. Therefore, “organizing learning around authentic problems, projects and cases help improve the likelihood of subsequent transfer”.

However, how authentic the problem should be is still a vague issue. As Heywood (2005) observed, the extent of the authenticity varies in real teaching practice due to people’s different preferences or the constraints of environments. Barab et al. (2000) also pointed out that authenticity “is most often poorly defined and definitely lacks a solid base of empirical research”. Likewise, Blumenfeld et al. (1991) found that there is “little systematic empirical
information about what problems students actually found valuable, interesting, or useful enough to work for long period”. Furthermore, “because students are open to explore all dimension of the problem, there is real difficulty of creating a rich problem with a consistent set of information” (Savery and Duffy, 1995).

Honebein et al. (1993) and Savery and Duffy (1995) suggested using the authentic learning environment to settle this problem. They defined the authentic learning environment at cognitive level and argued that “an authentic learning environment is one in which the cognitive demands, ie. the thinking required, are consistent with the cognitive demands in the environment for which we are preparing the learner”, thus the learner should be provided with the scientific activities which “present the same type of cognitive challenges”. However, learners’ cognitive demands are hard to quantify and to measure as well, thus difficult for practitioners to implement in project-based learning.

2.1.2.2 An end or final product

In project-based learning, a concrete final product which addresses the driving question is always required. It could be written work like essays or reports, oral work like presentations, or hands-on artifacts.

This feature of project-based learning is regarded as one of the differences between project-based learning and problem-based learning in that the latter does not necessarily require an end product or a clear and bound solution (Savin-Baden, 2003).

Concerning the function of the final product in project-based learning process, Helle et al. (2006) argued from the cognitive perspective that “the concrete artifact can serve as a boundary object facilitating continuous task-oriented interaction among students and teachers or among peers”. In addition, the process of learning while preparing the product can “serve to prevent the formation of misconceptions” (Blumenfeld et al., 1991). Furthermore, artifacts can be “rich enough to promote both depth and breadth of knowledge in their creation as well as demonstrate student mastery of the content” (Blumenfeld et al., 1991).
A boundary object is a concept in sociology to describe information used in different ways by different communities. This idea was introduced by Star, J.R. in 1989.

2.1.2.3 Student centredness in the learning process

Student centred learning can be said to be a key feature of the constructivist learning and teaching approaches, especially project-based learning, problem-based learning and other enquiry based methods of learning (Brown, 2004; Helle et al., 2006). Brown (2004) summarized three essential features of student centred learning: freedom of choice, students’ responsibility for their own learning and the creation of a supportive environment in which students can develop their potential. Thus, compared with students in the traditional lecture-based teaching environment, students in student centred learning environment have more control of their learning by having more free choices and more responsibilities, and the role of teachers is to guide and facilitate learning with less control over students.

Student-centredness is generally believed to be a strength of project-based learning as well as other similar constructivist approaches (Helle et al., 2006). Brown (2004) held that student-centred learning is distinct from teacher-centred learning in that the emphasis of the former is on the student as a person to develop while the emphasis of the latter is on the student as an individual to train. Such distinction reflects the humanistic point of view in education which aims at the development of the whole person, that is, both feelings and knowledge of learners are regarded as important in the learning process.

In project-based learning, students have the opportunity to “exercise choice and control regarding what to work on, how to work, and what products to generate” (Blumenfeld et al., 1991). Seen from the cognitive perspective, choice and control are critical to enhance students’ motivation in their learning (Blumenfeld et al., 1991; Deci and Ryan, 1987; Lepper, 1988), and learner control also provides students with the opportunity to utilise their prior knowledge and experience (Helle et al., 2006; Prince and Felder, 2006).
2.1.3 Types of Projects

As Heyhood (2005) observed, there are various ways of classifying [engineering] projects, but no one is entirely satisfactory. The reason, the author believes, might be that different classifications are made from different perspectives.

2.1.3.1 Classification by Individual and Group/team

In project-based learning, projects can mean individual projects or group projects. However, most of the recent research focuses on projects which are group-based. A major reason for this is the increasing social demand for graduates’ teamwork ability (Heywood, 2005).

In group projects, the team size varies from project to project and ranges from 2 students to the entire class, with group sizes of three, four and five most frequently mentioned in literature (Duston et al., 1997; Helle et al., 2006) It is argued that small teams may “run the risk of losing a large portion of its task force if one student drops the class”, while large groups may have the problem that some members do not contribute to the project (Duston et al., 1997) Generally speaking, it is believed that groups of 2-5 students are feasible for most purposes (Helle et al., 2006).

2.1.3.2 Classification by the Aim of Project

The aim of projects can be different. It is usually to “enable students to apply knowledge and techniques already acquired to an academic issue in a subject area already familiar to them”. This type of project usually represents the most traditional or conventional kind of independent activity in British universities, which Morgan termed as “project exercise” (Morgan, 1984, p222).

The aim of projects can also be broaden to “develop problem-solving abilities and a capacity for independent work”. This type of project, which Morgan termed as “project component”, is usually of interdisciplinary nature, and “does not necessarily build hierarchically upon knowledge and skills already acquired”, and usually “in parallel with other more conventionally taught course components” (Morgan, 1984, p222-223).
Concerning the purpose of project-based learning application, Hell et al. (2006) summarized three kinds of purposes and their corresponding types of projects:

- Provide the students with a very concrete and holistic experience regarding a certain process (eg: the construction process, the management of a project, etc.). When PBL is used in this sense, it is usually as an introduction to something (eg: the beginning of studies in a certain field or as a transition to working life);

- Promote the integration of subject material (and the ability to apply it as circumstances dictate), eg, the capstone experience at the end of a course or curriculum;

- Use as a method of guided discovery learning with the intention of promoting self-regulated deep-level learning (in this sense, the project is embedded in the course structure).

Morgan (1984) put forwarded an interesting dimension which he termed as project intention, which refers to “the main emphasis and aims of a particular project topic”. He classified two types of project topics: academic topics and real world issues. He held that in project-based learning, the aim of the real world issues is to derive some social benefit, and the difference between these two types of projects is similar to the distinction between pure and applied science (Morgan, 1984).

2.1.3.3 Classification by Student or Teacher control

Project-based learning is characteristic of student-centredness, yet “the relative influence of teachers and students is likely to vary considerably from activity to activity” (Morgan, 1984, p225).

1) Control of project selection

There are some arguments about “who chooses the project” in project-based learning. Based on
this classification, Ansell (1998) distinguished three types of projects in the engineering education context: professor-driven, student-driven, and client-driven projects. Professional driven projects refers that the teacher assigns the project; student-driven projects are those chosen by students; client-driven projects may be students themselves in the collegiate situations, or companies or industries in the industrial situations.

According to Heywood (2005), the advantages of the professor-driven project is that it can be a valuable aid to what is learnt in class, and can also be used to integrate what students have learned in several courses. By comparison, the student-driven project is likely to stimulate students’ motivation because of its likelihood to be within students’ interest area, and may raise the level of self confidence. However, for the less able students, they may have difficulties such as providing realistic alternative solutions and selecting the proper level of difficulty. Client-driven projects, on the other hand, are more likely to involve realistic constraints and pressures, and usually require work that “cuts across subject boundaries” (Heywood, 2005). In client-driven projects, students may be well motivated and have a great sense of responsibility (Duston et al. 1997). However, one potential limitation of client-driven projects is that, if the targets are not met, it may affect more parties involved (Heywood, 2005).

The choice, as Heywood (2005) suggested, ultimately depends on the objectives to be achieved in project-based earning.

2) Team formation
The ways of team member selection are also various. Broadly speaking, it ranges from students selecting their own team members to teacher allocating the team members (Dutson et al., 1997; Heywood, 2005). Allocated teams can either be randomly selected or “engineered to create teams containing a range of experience and abilities (Tucker and Rollo, 2006).

Self selecting groups can “minimize personal conflict and reduce the need for teacher intervention in disputes” (Tucker and Rollo, 2006). However, there is a danger that “like might group with like”, and that “too much cohesion in groups may lead to over-conformity in group
literature review thinking” (Ramirez et al., 1998; Schultz, 1998). In addition, it was found difficult to get a good mix of skills in each group or to avoid groups that are all leaders or followers (Schultz, 1998).

The teacher allocated groups are more like in reality, for example, simulating what happens in the engineering industry. The allocation can be on the basis of student academic background, prior experience, mixed academic years of students, mixed disciplines of students, mixed personality types, etc. (Clayton, 2000; Gates et al., 2000; Oakes et al., 2000; Ramirez et al., 1998; Tucker and Rollo, 2006).

Brickell et al. (1994) compared five ways of group allocation. They are: heterogeneous GAP and heterogeneous interest, heterogeneous GAP and homogeneous interest, homogeneous GAP and heterogeneous interest, homogeneous GAP and homogeneous interest, and self-select. They found that overall group selection had only slight effects on group performance, but generally the mixed perform better than self-selected groups (Brickell et al., 1994).

3) Control of project learning process
Here the control of project learning process refers to “whether students or teachers decide what is studied in project work and how it is studied” (Morgan, 1984, p225). Based on this classification, Kolmos (1996) classified three types of projects:

a) Assignment project or task project, which is characterized by considerable planning and control by the teachers / supervisors, and the problem and the subject as well as the methods are chosen beforehand;

b) Subject project, in which the students have a free choice “either of problem within the subject” or the problem will be given and the students have a free choice among a number of desired methods. The subjects are chosen beforehand;

c) Problem project, in which the problem will determine the choice of disciplines and methods.

In engineering science, Heywood (2005) argued that some work labeled as projects is actually an experimental investigation in that both are open ended and involve students’ freedom of
choosing what investigations they want to do. In contrast, he termed a similar project approach as guided project-based learning because it is highly structured and in the guided discovery mode (Heywood, 2005).

4) Control of project assessment

The feature of student-centredness in project-based learning makes its assessment subjective and difficult, especially in group projects, because the individual effort and individual achievement are often difficult to identify and reward (Duston et al., 1997).

The assessment of project-based learning can be made by the teacher, the student, such as self and peer assessment/review, or an outsider, such as the industrial panel members (Heywood, 2005; Leifer and Sheppard, 1997).

Besides the classifications discussed above, there are further other classifications such as project duration, course content, faculty involvement, etc.

2.1.4 The Underlying Learning Theories of Project-based learning

How learning occurs and how to integrate theory and practice well seem to be the never-ending issues in the educational field, which further influences pedagogical approaches, including project-based learning.

2.1.4.1 Constructivism

Learning theories can be categorized into three historical traditions: Rationalism, Associationism, and Constructivism. Rationalism argues that learning is based not so much on experience, but on revealing to ourselves the knowledge we are born with, through a process of logical deduction or rational discourse. The advocates are Plato, Descartes, Freud, Chomsky, etc.; Associationism argued that experience is the basis of all learning and knowledge, and the infinite variety of the world should be dealt with by associating aspects that commonly occur together. Proponents include Aristotle, Locke, Hobbes, Hume, Thorndike, Skinner, and others.
It can be seen that rationalism and associationism represent quite different theories about the nature of learning and knowledge, and are based on contrasting models of human nature. Constructivism tries to strike the balance between rationalism and associationism, holding that experience is important to learning (associationism), but there has to be something already present in the mind before people make sense of reality (rationalism). However, what is supposed to be innate here is not pure ideas as advocated in rationalism, but abstract mental representation-forming rules called schemata, based on which constructs or models of reality are constructed out of actual experience with reality. The essence of learning in constructivism, then, is the development of concepts or schemata by concrete action on the environment, or context.

Thus, from the perspective of constructivism, knowledge is a continuous construction and is constructed through the individual’s interaction with the environment, and learners are not passive recipients of information, but actively construct their own knowledge and skills on the basis of their prior knowledge, starting from what they already know and can do, processing actively the information they encounter, and, as a consequence, deriving new meanings and acquiring new skills (De Corte, 1996). Representatives of constructivism include Kant, Piaget, Bartlett, etc.

To be compatible with the principles of the constructivist model of learning, effective instruction must involve experiences that can induce students to construct knowledge for themselves on the basis of necessary adjustment or rejection to their prior knowledge through the individuals’ interaction with actual experiences (De Corte, 1996; Prince and Felder, 2006). Project-based learning is one such constructivist learning approach.

2.1.4.2 Vygotsky’s Social–cultural Psychology

Vygotsky’s social-cultural concept emphasized the social nature of learning by holding that each instance of human behaviour is to be considered in light of its history and social-cultural context. According to Vygosky, learning takes place primarily on the social, inter-psychological plane, and only secondarily on the intra-psychological plane when a learner internalises what has first been experienced in social interaction (De Corte, 1996). The ideal state for learning is what
Vygotsky called *zone of proximal development*, which refers to the distance between the learner’s actual state of development, determined by independent problem-solving, and the potential level of development that he or she can reach through the guidance of adults or collaboration with peers. Accordingly, Vygotsky argued that through social interaction students may reach a higher state of development than they would achieve by working and studying on their own. (Helle et al., 2006), and meaning is not simply constructed, but co-constructed (Prince and Felder, 2006).

An important dimension which is rooted in Vygotsky’s social–cultural psychology is activity theory, initiated by Leont'ev. Activity theory also focuses on social interaction, but its concern is not the locus of mind, but social-cultural context, or activity. In activity theory, the unit of analysis is an activity, and the activity itself is the context (Nadi, 1996). Thus, rather than focusing on knowledge states and representations, it “focuses on activities in which people are engaged, the nature of their tools, the social relationships, the contextual factors, and the goals and outcomes of activity” (Hung, 1999).

In activity theory, a key concept is meditation by artifacts. Here artifacts broadly include instruments, signs, languages and machines, and are believed to be persistent structures stretching across activities through time and space, and are created by learners to control their own behaviour (Kuutti, 1991; Nadi, 1996). One feature of project-based learning is artifacts, or end products. Blumenfeld et al. (1991) defined artifacts in project-based learning as “the sharable and critiquable externalization of students’ cognitive work”. It is through the process of generating the artifacts that students construct their knowledge, thus, students’ freedom to generate artifacts are considered to be critical in project-based learning (Blumenfeld et al., 1991).

Influenced by the theories of Vygotsky and Leont’ev, Bruner (1986) held that “learning in most settings is a communal activity, a sharing of the culture”, and “education is about transmitting beliefs and practices of cultures” (Bruner, 1996). He suggested that education should “provide the balance between teaching specific beliefs and providing learners the ‘culture toolkit’ *
through enculturation, that is, through entering and picking up the values of a community or
culture by practicing the trade of community”, so that students can be helped to use the cultural
 toolkit of meaning making and reality construction (Bruner, 1996; Hung, 1999).

In activity theory, artifacts carry with themselves a peculiar culture and history (Kuutti, 1991;
Nadi, 1996). The cultural challenges were also identified in different models of problem-based
learning and project-based learning (Kolmos et al., 2009). It is recognized that the practical
conditions in engineering are quite different from those in, say, the health sciences. For example,
the knowledge structure is more hierarchical in engineering (Houghton, 2004). Therefore, for
the learning to be effective or successful, it should be organized in accordance with the cultural
practices that are familiar to learners and staff (Kolmos et al., 2009).

*Culture toolkit includes a variety of tools a given culture uses to make sense of the world, such
as culturally developed representational systems, technologies, and ways of thought."

2.1.4.3 Situated Cognition

The central concepts of situated cognition are practice, community of practice, and participation
(Hung, 1999). The situated view conceives learning in terms of increasing participation in
communities of practice, and knowledge as fundamentally distributed. A key assumption of
situated cognition is that the person and the environment cannot be separated in any analysis of
learning; but are each part of a mutual constructed whole (Bredo, 1994). In other words, the
environment is an integral part of cognitive activity, not merely a set of circumstances in which
context-independent cognitive processes are performed (Dillenburg et al., 1996), as Nadi (1996)
pointed out, “situated action models emphasize the emergent, contingent nature of human activity,
the way activity grows directly out of the particularities of a given situation.” Thus, knowing is
located in relations among practitioners, their practice, and their social organization and political
economy of communities of practice (Lave and Wenger, 1991), and a person’s knowledge is “in
his or her ability to find and use the resources, not in having mental versions of maps and
instructions as the basis for all reasoning and action” (De Corde, 1996).
A major implication of this view of learning and knowledge is the need to anchor learning in authentic, real-life social and physical contexts that are representative of the situations in which students will have to use their knowledge and skills afterwards (Brown et al., 1989; De Corde, 1996). Hence, it is important that education should provide students with opportunities of authentic practices and social interaction such as teamwork (Fruchter and Emery, 2000; Lave and Wenger, 1991; Tynjala et al., 2003). Project-based learning is such kind of approach which places students in realistic, contextualized problem-solving environments, and which is often group-based (Blumenfeld et al., 1991; Heywood, 2005).

2.1.4.4 Dewey’s Pragmatism

One central feature of Dewey’s pragmatism is “learning by doing”. Dewey believed that education should engage with and enlarge experience, and advocated learning from projects rather than from isolated problems. In his view, opportunities should be given for students to actively explore knowledge, and it is through students’ active exploration that the development of students’ thinking can possibly be realized. Thus, he was critical of the education based on transmitting knowledge and contrasted learning from text and teachers with learning from experience. The teachers’ role in education, in Dewey’s eyes, was not to impose direction, but to provide approval and encouragement (Morgan, 1984).

Project-based learning manifested Dewey’s educational philosophy in that learning is no longer a process of knowledge transmission from the teacher to students, but a process of students’ active involvement in project activities, and at the same time students take different degrees of control in their learning by taking some responsibility for designing their own studies.

2.1.5 The Effectiveness Issue of Project-based learning

2.1.5.1 Lessons Learnt from Early Years’ Project-based learning Practice

There is a long tradition of using projects in professional education in Europe, especially in the architectural and engineering studies (Heitmann, 1996; Heywood, 2005). However, it was generally recognized that project method was first brought into general and vocational education on a wide scale in the 1920s, as part of the progressive education during the progressive
movement in the US (Heitmann, 1996; Morgan, 1984).

The early years’ application of project-based learning in the educational field can be said to be an on and off process, with the flourish of the progressive movement from 1920s in the US and its collapse by the late 1950s, and with the attempts at reforms of curriculum and instruction in the 1960s using hands-on and discovery learning as the central theme (Blumenfeld et al., 1991; Knoll, 1997).

The early years’ application of project-based learning is characterized by some outstanding and successful solutions and many failures as well (Blumenfeld et al., 1991; Heitmann, 1996). Heitmann (1996) argued that the reason for those failures might lie in its ambitious intentions. Blumenfeld et al. (1991) explored the reasons that project-based learning were not as widespread desired from three aspects as follows:

1) Insufficient appreciation for the complex nature of student motivation and knowledge required to engage in cognitively difficult work.

2) Little regard for considering questions from the point of view of students (as distinguished from experts).

3) Little attention was paid to the nature and extent of teacher knowledge and commitment and the complexity of classroom organization.

Accordingly, Blumenfeld et al. (1991) suggested that, to realize the potential of project-based learning, projects should be designed to marshal, generate and sustain the motivation and thoughtfulness of students, and teachers should be supported to create such type of instruction by paying close attention to the design of project questions and associated activities, and to the strategies to improve teacher’s implementation of projects. From the perspective of assessment, Morgan (1984) further suggested that in project-based learning ways of assessment should be more congruent with the broader aims of higher education.

2.1.5.2 Current Issues in the Research on Project-based learning

\[\text{Literature Review}\]
1) The variety and overlapping of constructivist pedagogical approaches in higher education

In recent decades, with the development of cognitive psychology, the deeper understanding of student learning, the new development of educational technology tools and a wider range of achievement expected of the graduates, project-based learning is enjoying a fresh outburst of attention (Blumenfeld et al., 1991; Helle et al., 2006).

At the same time, other similar constructivist teaching and learning approaches are also advocated and increasingly applied in different subjects in both schools and higher education, including problem-based learning, experiential learning, work based learning, action learning, service learning, enquiry based learning, active learning, collaborative/cooperative learning, small group learning, activity based/led learning, task based learning, etc. (Barrows and Tamblyn, 1980; Boud and Feletti, 1999; Brown, 2004; Helle et al., 2006; Johnson et al., 1998; Kolb, 1984, 2000; Schmidt and Moust, 2000; Smith and O’Neil, 2003).

Under the umbrella of constructivism, the different new pedagogical approaches have as many differences as similarities. The various student-centered approaches often overlap each other in real application situations, which cause confusion in understanding their similarities and differences.

a) Project-based learning and problem-based learning

Problem-based learning is a model developed in 1970s in medical education in Canada and then widespread to other fields. Problem-based learning begins when students are confronted with an open-ended, ill-structured, authentic (real-world) problem and work in teams to identify learning needs and develop a viable solution, with instructors acting as facilitators rather than primary sources of information (Boud and Feletti, 1999).

Like project-based learning, problem-based learning is not only an instructional approach, but also a curricular approach, such as the problem-based learning curricula at the University of Delaware and Samford University in the United States, McMaster University in Canada, the University of Maastricht in the Netherlands, Linkoping University in Sweden and the University
of Newcastle in Australia, etc (Macdonald, 2001; Prince and Felder, 2006). The Aalborg University is an example that uses both project-based learning and problem-based learning in their curriculum (Prince and Felder, 2006).

At the instructional level, confusion is often caused between project-based learning and problem-based learning, mostly because both of them are student-centred learning using problems as the driver of their learning activities.

According to Boud (1985), the principle idea behind problem-based learning is that “the starting point for learning should be a problem, a query, or a puzzle that the learner wishes to solve”. Savin-Baden (2000) held that “there are many different ways of implementing problem-based learning, …, however, what will be similar will be the focus of learning around problem scenarios rather than discrete subjects”. Thus, using problems is regarded as one of the similarities between the two approaches (Hmelo-Silver, 2004; Prince and Felder, 2006).

However, concerning the type of problems used in problem-based learning and project-based science, Hmelo-Silver (2004) articulated the difference between the two and held that “problem-based learning uses realistic, ill-structured problems” while in project-based science, “the problem is a driving question”. By comparison, Prince and Felder (2006) argued the differences of problems used in these two approaches in terms of the scope, holding that “a project typically has broader scope and may encompass several problems”.

Concerning the role of the problem and the learning outcomes, Hmelo-Silver (2004) argued that the problem in problem-based learning is the focus for acquiring knowledge and reasoning strategies”, while in project-based science, “the problem is the focus for science inquiry as students must determine how they will answer their question”. Generally, the emphasis of project-based learning is believed to be on the application of knowledge, while the emphasis of problem-based learning is on the acquisition of knowledge” (Perrenet et al., 2000; Prince and Fedler, 2006). More specifically, the concern of project-based learning is the development of cognitive and practical skills, whereas the concern of problem-based learning is the acquisition
Accordingly, concerning the role of the teacher, Kolmos (1996) differentiated the role of a “process-oriented supervisor” in problem-based learning with the role of a “product-oriented supervisor” in project-based learning. Likewise, Helle et al. (2006) pointed out that students’ activity in problem-based learning is directed to “studying” whereas in project-based learning it is directed to “constructing the product”.

Concerning the problem solving process and specific learning tools employed, Hmelo-Silver (2004) argued that problem-based learning involves specific PBL learning cycle in the learning process, while in project-based science students engage in scientific inquiry cycles; in terms of the tools, he argued that problem-based learning “uses a simpler tool, a structured whiteboard with lists of facts, ideas (i.e. hypothesis), learning issues, and action plans”, while project-based science uses “a variety of computer-based tools to scaffold students problem solving” (Hmelo-Silver, 2004, p239).

Savin-Baden (2003) listed the detailed differences between problem-based learning and project-based learning. Therefore, the situation is like that described by Kolmos et al. (2009), “As both types of PBL models (project-based learning and problem-based learning) began to spread to other universities and more universities… there is a clear trend to separate the two models and distinguish between the problem-based learning and project-based learning models”.

Despite the differences argued about between project-based learning and problem-based learning, and the arguments about which one is more suitable, for example, in engineering education, (Ellis et al., 2003; Hadgraft, 1991; Parrenet et al., 2000; Woods, 1997), in practice, the distinction between these two approaches is not always clear, and sometimes can be quite blurred (Prince and Fedler, 2006). This is especially the case in engineering education, in which “problem-based learning is sometimes called project-based learning when the problems are centered around a project” (Fruchter and Emery, 1999; Zolin et al., 2003), “What one institution practices as problem-based learning may look very much like what another institution practices
as project work” Kolmos (1996), “sometimes project-based learning and problem-based learning mean the same thing, at other times they don’t” (Heywood, 2005, p224), and sometimes the programmes may include features of both of the two approaches (Prince and Felder, 2006).

The reasons for such chaos in the application of these two approaches can be twofold: one the one hand, in project-based learning, there exist many various types of project work (see the discussion in 2.1.3); on the other hand, problem-based learning is “characterized by flexibility and diversity in the sense that it can be implemented in a variety of ways in and across different subjects and disciplines in diverse contexts” (Savin-Baden, 2000, p3). Such variety of its implementation can range from the so-called “pure form” of problem-based learning, which embraces the problem-oriented approach without traditional lectures, for example, the Seven Jump procedures used in medical education (Schmidt, 1983), to the “hybrid” version of problem-based learning, which involves projects, formal tuition and traditional lectures, and even to the practice which just uses smaller elements of problem-based learning (Macdonald, 2001; Savin-Baden, 2008).

Kolmos et al. (2009) pointed out the limitation of the recent distinctions between problem-based learning and project-based learning by arguing that “most of these definitions attempted to narrow down the conceptual understanding of PBL (problem-based learning and project-based learning) and define them solely through one particular practice, subject area or cultural setting”. In order to “allow variation in the development of PBL models and allow them to be adjusted to a given institution, they defined PBL as learning principles in three approaches: learning, content and social, which cross the PBL models and unify the problem-based learning and project-based learning approaches (Kolmos et al., 2009).

Based on the PBL learning principles, Barrows’ PBL taxonomy and Savin-Baden’s five PBL models, Kolmos et al. (2009) put forward a model for problem and project-based alignment, which covers seven elementary elements that they think must be aligned in a problem and project-based curriculum, including objectives and knowledge, types of problems and projects,
progression, size and duration, academic staff and facilitation, space and organization, assessment and evaluation and course or system approach. They suggested that this model “could be a theoretical starting point for most PBL research in order to identify the coherence among curriculum elements in the PBL practice and especially to study the impact of a chosen practice on students’ learning and students’ outcomes (Kolmos et al., 2009).

b) Project-based learning and collaborative/ cooperative learning

Collaboration among students is believed to be “a cornerstone of the newer approaches to learning” (Blumenfeld et al., 1991, p377). However, there is a complex debate about the distinction between collaboration and cooperation (Dellenbourg et al., 1996).

Broadly speaking, collaborative learning can refer to any instructional method in which students work together in small groups towards a common goal, and thus it can encompass all group-based instructional methods, including cooperative learning (Prince, 2004), and some people use these terms interchangeably (Dellenbourg et al., 1996).

In terms of the restricted definition, the extent of shared work in the two approaches is considered to be different: collaboration involves the “mutual engagement of participants in a coordinated effort to solve the problem together”, whereas cooperative work “is accomplished by the division of labor among participants, as an activity where each person is responsible for a portion of the problem solving” (Teasley and Roschelle, 1996). Therefore, the core emphasis of collaborative learning is “on student interaction rather than on learning as a solitary activity”, while the core emphasis of cooperative learning is “on cooperative incentives rather than on competition to promote learning” (Prince, 2004), and collaborative learning is characterized by relatively unstructured process, compared with cooperative learning which is generally described as a structured, systematic instructional strategy (Springer et al., 1999).

Collaborative learning and cooperative learning are concepts often mentioned in connection with student projects (Helle et al., 2006). In project-based learning, because the project work is usually divided among participants, with the aim of constructing a shared outcome, thus
project-based learning usually involves both cooperative and collaborative elements (Helle et al., 2006).

There are various forms, or models, of cooperative learning. The most common model is that of Johnson, Johnson and Smith, which encompasses five specific tenets: 1) individual accountability; 2) mutual interdependence; 3) face to face promotive interaction; 4) appropriate practice of interpersonal skills; 5) regular self-assessment of team functioning (Johnson, Johnson and Smith, 1998). Other well-known forms include Aronson's Jigsaw (1978), Slavin’s Student Team Learning (1995), Sharan’s Group Investigation (1990) (from Springer et al., 1999). Kagan (1994) has ever described more than 100 forms of cooperative learning at various educational levels, and the forms of cooperative learning mixed with collaborative learning are believed to more than that (Springer et al., 1999).

Research has shown that careful designed collaborative/cooperative learning programs can improve student achievement and attitudes (Springer et al., 1999; Johnson et al., 2000), but at the same time, group work may “diminish thoughtfulness by encouraging reliance on others as resources, thereby decreasing personal responsibility and independent thinking” (Blumenfeld et al., 1991, p377). Therefore, students' interpersonal skills and self-directed learning ability in such group work, like being able to discuss ideas and communicate clearly, considering alternatives systematically, monitoring their own understanding, comparing their point of view with that of others, and asking clear questions, are believed to be of central importance for students to benefit from collaborative or cooperative work (Blumenfeld et al., 1991; Johnson and Johnson, 1990).

c) Project-based learning and experiential learning

Experiential learning theory was put forwarded by Kolb (1971, 1984), which aims to “provide a holistic model of the learning process and a multilinear model of adult development” (Kolb, 1984; Kolb et al., 1999). Kolb (1984, 2005) defined learning as the process of transforming experience into knowledge, and suggested that the learning based on one’s own experience is more effective (Brown, 2004). He emphasized the role of reflection in the learning process,
proposing that based on the reflection on one’s learning, a theoretical understanding of what has been learnt can be developed and further applied to new situations. Such a cycle formed his experiential learning model, which involves four dialectically related learning modes through which the learning takes place: Concrete Experience, Reflective Observation, Abstract Conceptualization and Active Experimentation (Kolb, 1984; Kolb and Kolb, 2005).

Based on individuals’ preference for the different combinations of the four learning modes, four basic learning styles were identified, namely, assimilating, converging, accommodating and diverging, which were further expanded to nine learning styles (Hunt, 1987; Kolb, 1984; Kolb and Kolb, 2005). These learning styles were found to be influenced by personality type, educational specialization, career choice, current job roles and tasks, and cultural influence (Kolb and Kolb, 2005).

The central idea of experiential learning and project-based learning can both be dated back to a central feature of Dewey’s educational philosophy, that is, learning from experience (Kolb, 1984; Morgan, 1984). Experiential learning bears a resemblance to the original model of project-based learning (Helle et al., 2006). Project-based learning is in essence experiential learning, but project-based learning manifested Dewey’s educational philosophy more by students’ active involvement in learning as they take some responsibility for designing their own studies (Morgan, 1984).

Reflection is a key concept in Kolb’s experiential learning theory. This term is similar to reflective thinking, or metacognitive skills, or self-regulative knowledge (Tynjala et al., 2003). Schön (1983) distinguished two types of reflection, reflection in action, which happens during the immediate decision making, and reflection on action, which happens afterwards and may provides a deeper view on what has been learned. Brown (2004) argued that “neither reflection nor experience per se necessarily leads to learning or good teaching”. Tynjala et al. (2003) suggested that problem-solving is “a mediating tool for integration of the different components of expert knowledge”, namely theoretical knowledge, practical knowledge and self-regulative knowledge (i.e. reflection), thus students should be provided with opportunities to solve
complex, ill-defined problems in their experiential learning process. Thus, project-based learning, which is characteristic of problem orientation, may help learners engage in reflecting in action and on action, and promote the process of knowledge reconstruction for the development of professional expertise (Helle et al., 2006; Tynjala et al., 2003).

d) Project-based learning and work-based learning

Work-based learning can refer to both employees’ learning and students’ learning through “practice periods, working life-oriented projects, excursions, adult students’ work experience or other forms of working life connections” (Tynjala et al., 2003). It is “university programmes that bring together universities and work organizations to create new learning opportunities in workplaces (Boud et al., 2001, p4).

There is a great variety in connecting work with university curricula, and there are also various ways of organizing students’ learning through their work (Brennan et al. 1996; Stern et al. 1998; Trigwell and Reid, 1998). Broadly speaking, work-based learning may take various forms, including working life-oriented projects, sandwich courses, an alternating sequence of placements, part-time employment, etc (Tynjala et al., 2003). In the UK, work-based learning mainly refers to the placement in the Sandwich courses, initially in areas of engineering, and later expanded to a wide range of other fields, for example, business studies (Faconer and Pettigrew, 2001).

Project-based learning is believed to be able to “bring working life problems closer to students” (Tynjala et al., 2003), and work-based learning and project-based learning overlap “provided that learning takes place in the form of project studies” (Helle et al., 2006). The three way partnerships between the learner, the university and the employer in the work-based learning based on real-time, work-based projects very much resemble the client-driven type of project work in project-based learning.

e) Project-based learning and service learning

Service learning is a term mainly used in the U SA, which is similar to work-based learning.

Literature Review
The main difference between the two is that work-based learning emphasizes the occupational development of the individuals while service learning takes serving the good of the community and society as its ideological principle (Tynjala et al., 2003). Thus, service learning is defined as “a form of experiential education in which students engage in activities that address human and community needs together with structured opportunities intentionally designed to promote student learning and development” (Jacoby, 1996). Put it simply, service learning is an approach which “integrates community service into academic learning” (Tsang et al., 2001).

Service learning is a form of experiential education, and reflection and reciprocity are held to be its key concepts (Jacoby, 1996). For reflection, opportunities should be provided for participants to receive feedback from the persons being served, as well as from peers and program leaders, and for reciprocity the relation between the needs determined by the community members and the service tasks defined by the learners should be well developed (Jacoby, 1996).

In engineering education, service learning usually involves various kinds of projects (Oaks et al., 2002; Tsang et al., 2001). Again service learning very much resembles the client-driven type of project work in project-based learning. As such, service learning overlaps with project-based learning as long as sufficient attention is paid on reflection and reciprocity (Tsang et al., 2001).

From the discussion above, it can be seen that the various constructivist approaches overlap with each other in some circumstances.

For example, experiential learning is believed to bear a resemblance to the original model of project-based learning (Helle et al., 2006); project-based learning overlap with work based learning and service learning provided that the learning involves project studies (Helle et al., 2006); project-based learning and problem-based learning, as well as quite many other new pedagogical approaches, involve collaborative and/or cooperative learning (Helle et al., 2006; Prince, 2004; Prince and Felder, 2006); problem-based learning covers various ways of implementation in practice, ranging from the “pure form”, which embraces the problem-centred approach without traditional lectures, to “hybrid form” with different degrees of projects, formal
tuition and traditional lectures (Macdonald, 2001; Savin-Baden, 2008), and in practice, the distinction between project-based learning and problem-based learning is sometimes quite blurred, especially in engineering pedagogical practice (Kolmas, 1996; Prince and Felder, 2006; van Barneveld and Strobel, 2009).

On the other hand, as an educational activity, project-based learning itself can be conceptualized on a number of dimensions and are also implemented in various ways with various student and teacher control in the learning process. Such variety and complexity, and make it quite difficult to define it in a specific and precise way (as can be seen in section 2.1.3. types of projects).

In summary, the overlapping between project-based learning and other constructivist pedagogical approaches as well as the different ways of implementing project-based learning tend to cause the chaos in the project-based learning application, and further make it hard to define and interpret precisely what is being studied in the research on their effectiveness.

2) The comparison of effectiveness between constructivist pedagogical approaches and traditional approaches in PBL

In recent decades with the increasing implementation of project-based learning as well as other constructivist pedagogical approaches in higher education, much attention was paid by researchers to study the effectiveness of these constructivist approaches, especially the effectiveness of problem-based learning compared with the traditional lecture based approach, which also shed light on the studies of effectiveness of project-based learning.

a) Insights from the comparison of effectiveness between problem-based learning and traditional approaches

Problem-based learning originated from the medical education. Therefore, the research on its effectiveness is relatively thorough and mature in this field. Generally speaking, research on the comparison of the effectiveness of problem-based learning and traditional approaches in medical education can be divided into two phases:
Phase 1: from 1990-1999

In the 1990s, four meta-analysis of the effectiveness of problem-based learning were conducted compared with that of the traditional lecture-based teaching approach, and all of them were focused on medical education.

Albanese and Mitchell (1993) reviewed problem-based learning literature from 1972 to 1992, and found that problem-based learning is more nurturing and enjoyable compared with conventional instruction. However, PBL students tended to score lower on basic sciences examinations and felt less well prepared in the basic sciences. Furthermore, there appeared to be gaps in problem-based learning students’ cognitive knowledge base that could affect practice outcomes. In addition, the cost of problem-based learning, the weaknesses in the criteria used to assess the outcomes, and general weaknesses in study design are all the problems being identified.

Vermon and Blake (1993) conducted a meta-analysis evaluation on the studies of problem-based learning from 1970 to 1992, and found that the problem-based learning approach was equal to traditional approaches in terms of conventional tests of knowledge, but the students in problem-based learning exhibited better clinical problem-solving skills.

Berkson (1993) made a narrative review of 10 problem-based learning studies before 1992, and found that no evidence showed that problem-based learning was better than traditional approach in terms of problem solving skills and imparting knowledge. However, results indicated that students and teachers favored problem-based learning, and students in problem-based learning put more emphasis on meaning construction than memory reproduction.

Kalaian et al. (1999) conducted meta-analysis of problem-based learning studies from 1970 to 1997, and their findings were consistent with previous ones that traditional approach is better than problem-based learning in terms of basic science knowledge, while problem-based learning is better than traditional approach in terms of clinical knowledge and skills.
Generally speaking, the findings conducted in the early 1990s indicated that students from problem-based learning curricula had better performance on assessment of clinical skills and problem-solving. They were also more satisfied with their learning environments. There were, however, mixed results between problem-based learning students and their counterparts in traditional approach with respect to the knowledge improvement.

Phase 2: from the year of 2000 onwards

From the beginning of the 21st century, the debates on the effectiveness of problem-based learning became heated both in theory and in empirical studies, especially in medical education field.

The debate seemed to start from the research by Colliver (2000) and Newman (2003), who reported conflicting results compared with the previous findings of effectiveness of problem-based learning in the 1990s.

Colliver (2000) analyzed eight studies from 1992 to 1998 comparing curriculum tracks and found that literature did not provide convincing evidence that problem-based learning was more effective than traditional approach in terms of knowledge base and clinical performance. He argued that the weak theory of problem-based learning and the loose tie between theory and research might be the reasons for the ineffectiveness of problem-based learning.

Newman (2003, 2004) reported a systematic review and meta-analysis on the effectiveness of problem-based learning in higher education programs for health professionals and presented mixed results in measures of accumulation of knowledge. Outcomes from this review varied, with advantages for problem-based learning students in measures such as study approaches and satisfaction, and mixed results in terms of application and accumulation of knowledge, the latter speaking in favor of traditional curricula in some studies. Based on his findings, Newman argued that “the existing overviews of the field do not provide high quality evidence with which to provide robust answers to questions about the effectiveness of problem-based learning” (Newman, 2003, 2004).
Dochy et al. (2003) reviewed 43 studies of problem-based learning and found positive effects of problem-based learning on students’ ability to apply knowledge, yet no significant differences on measurements of knowledge between problem-based learning and traditional approach.

Contrasted with the negative findings above, Gijbels et al. (2005) reviewed 40 studies between 1976 and 2000, and found that problem-based learning students performed better at knowledge levels. In terms of conceptual knowledge assessment, students of problem-based learning performed equally well as their counterparts in traditional approach. Their study indicated the potential influence of the assessment strategy and tool on the measurement of the learning outcomes: the better the capacity of the assessment instrument, the greater the ascertained effect of problem-based learning.

Strobel and Barnveld (2009) reviewed the studies of the meta-analytical research on the effectiveness of problem-based learning from 1992 onwards by using the measurement of meta-synthesis, which is a qualitative methodology and can account for differences in the conceptualizations and measurements of problem-based learning effectiveness. Their findings indicated that problem-based learning is superior in terms of long term retention of knowledge, skill development and satisfaction, by comparison, the traditional approach is better in terms of short term retention of knowledge. They concluded that problem-based learning is more effective to train competent and skilled practitioners compared with traditional instruction.

Although so many studies have been conducted of effectiveness of problem-based learning compared with traditional approach, with the existing of the conflicting findings, it seems that there is still no consensus on the value of problem-based learning.

Against the situation of the conflicting reports of the effectiveness of the constructivist approaches, Kirschner et al. (2006) analyzed what they called minimum guided instructional approaches, including constructivist, discovery, problem-based, experiential, and enquiry-based approaches, in the context of knowledge of human cognitive architecture, expert-novice differences and cognitive load. They argued that minimum guided instructional instruction is
less effective and efficient than instructional approaches, and that the advantage of guidance begins to recede only when learners have sufficiently high prior knowledge to provide “internal” guidance. Kirschner et al.’s argument seemed to reflect the fact that constructivist approaches as a whole have been under criticism for their being unproven, atheoretical and impractical (Land and Hannafin, 2000).

By comparison, in reply to the negative findings of effectiveness of problem-based learning, Norman and Schmidt (2000) argued that to truly understand the complexity of learning interaction and to achieve practical goals, a systematic research programme is necessary which encompasses all aspects from theory building and testing which is conducted with rigorous experimental design to program evaluation in realistic settings.

b) Problems in the research on the effectiveness of project-based learning

Like the research conducted on the effectiveness of problem-based learning, Helle et al. (2006) made a systematic review of empirical studies of project-based learning in various subjects in post secondary education published from 1960s to 2000. Based on the analysis of 28 studies, they found that most of the studies were course descriptions focusing on individual course implementation. Although some effects were found, including the increase in self-confidence and knowledge learning, changed way of going about work, positive effects on student satisfaction, enjoyment, interest or motivation, it was noted that serious attempts to measure the impact of project work on learning are scarce, thus most of the findings lack rigid research basis.

Generally speaking, problems in the research on the effectiveness of project-based learning are in the following two aspects:

1) Multiple and/or conflicting effects of learning variables

When analyzing the effectiveness of constructivist pedagogical approaches, it should be noted that learning is a complex process which involves very many controllable and uncontrollable variables. The effects of these variables on the learning process, as Norman and Schmidt (2000)
pointed out, are multiple, and sometimes even conflicting with each other, such as the positive effect of teamwork while at the same time the negative effect of self directed learning on student academic achievements in the context of problem-based learning. Since different implementations of the constructivist pedagogical approaches may emphasize different variables or emphasize the same variables to different extent, the research findings of the overall effectiveness of the new pedagogical approaches are bound to be confusing unless what is being examined has been carefully specified (Prince, 2004). On the other hand, the variables in the learning process may affect more than one learning outcome, thus a broad range of learning outcomes is also suggested to be considered (Norman and Schmidt, 2000; Prince, 2004).

2) Flawed research methodology
The lack of methodological and conceptual clarity in the research of the effectiveness of the constructivist pedagogical approach was criticized by many researchers (Mamede et al., 2006; Norman, 2006; Prince, 2004; Sanson-Fisher and Lynagh, 2005). To date, the arguments have mainly centred on the strengths of experimental approaches and randomized experimental design (Mamede et al., 2006; Norman, 2006), the use of structural equations modeling (Norman and Schmidt, 2000), and the limitation of meta-analysis used in the research literature so far (Prince, 2004). The lack of qualitative research was also identified (Kolmos et al., 2009).

2.1.6 Summary
With these problems existing in current research, the effectiveness issue of the constructivist pedagogical approaches, including project-based learning, is far from being settled. The conflicting research findings of student achievement, different ways of implementation, multiple effects of variables on learning outcomes and flawed research methodology make the effectiveness issue controversial and complex, which further affects the effective implementation of these constructivist pedagogical approaches in practice.
2.2 ENGINEERING EDUCATION

Engineering education is believed to be a subject “of more studies and reviews, formal and informal, than any other domain of professional education”, and has “undergone continuous reforms since college classrooms challenged apprenticeships and hands-on training in the last third of the nineteenth century” (Seely, 2005). Although the change in engineering education has been a continuous topic of discussion among engineering educators for the past century, during specific period the intensity of discussion increase significantly. The past decade has been one of those periods with the efforts on the engineering education reform focusing on the change of curriculum and pedagogy and aiming to prepare more competent engineers fit for the new century (Goldberg, 1994; Prados, 1998; Ruprecht, 2000; Sheppard, 2005; Wulf, 1998).

2.2.1 Current Situation of Engineering Education in Higher Education

New challenges have been confronted in engineering education from the end of last century, including the shift from defense to commercial competition as a major driver for engineering employment, the impact of exploding information technology on education and practice, the globalization of both manufacturing and service delivery, and the imperatives of environmental protection and sustainable development, all of which are dramatically changing the environment for engineering practice (Prados, 1998; Schachterle and Vinther, 1996).

In addition, most of today’s engineers, regardless of their disciplines, are working in a variety of emerging fields, including biotechnology and nanotechnology, and the skills they are asked have to keep changing (Grose, 2006).

In the 1990s studies were conducted in many countries to determine the technical and personal abilities required of engineers by industry (Boeing, 1999; Nicolai. 1998). Industry and professions are looking for greater breadth in their graduates as well as greater specialization in particular cases (Nicolai. 1998; RAE, 2005). These studies have informed reviews of engineering education and have had a major influence on the revision of national accreditation criteria for engineering programs in countries such as the outcomes-based US ABET 2000, UK SPEC 2004, IEAUST in Australia (Crosthwaite and Cameron, 2006) and Eurace (2005) in
Europe which shifted emphasis from “what is being taught” to “what is being learned” (Mills and Treagust, 2003). Consequently, the engineering curriculum has undergone great changes as well (Heitmann, 2005; Ruprecht, 2000; Seely, 2005).

A comparison between the accreditation criteria in the major countries mentioned above has been made to show the required attributes of today’s engineering graduates:
Table 2.2. Required Attributes in engineering graduates- knowledge & understanding.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic science and Maths</td>
<td>basic science and mathematics</td>
<td>the scientific and mathematical principles</td>
<td>an ability to apply knowledge of mathematics, science</td>
<td>ability to apply knowledge of basic science</td>
</tr>
<tr>
<td>Engineering science principles</td>
<td>engineering discipline</td>
<td>the key aspects and concepts of their branch of engineering; coherent knowledge of their branch of engineering including some at the forefront of the branch</td>
<td>knowledge of engineering; a knowledge of contemporary issues</td>
<td>engineering fundamentals</td>
</tr>
<tr>
<td>Specialist engineering knowledge</td>
<td>multidisciplinary engineering context</td>
<td>awareness of the wider multidisciplinary context of engineering</td>
<td>in-depth technical competence in at least one engineering discipline</td>
<td></td>
</tr>
<tr>
<td>Economics</td>
<td>economic considerations</td>
<td>transferable skills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business and management</td>
<td>commercial considerations</td>
<td>project management and business practice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental awareness</td>
<td>environmental considerations</td>
<td>environmental context,</td>
<td></td>
<td>environmental responsibilities</td>
</tr>
<tr>
<td>Ethics</td>
<td>ethical considerations; professional conduct</td>
<td>professional ethics responsibilities and norms of engineering practice</td>
<td>an understanding of professional and ethical responsibility</td>
<td>understanding of and commitment to professional and ethical responsibilities</td>
</tr>
<tr>
<td>Others</td>
<td>social considerations; legal requirements; sustainable development (specific)</td>
<td>societal health; safety and legal issues</td>
<td>the broad education necessary to understand the impact of engineering solutions in a global and societal context</td>
<td>social, cultural, global responsibility; understanding the need for sustainable development</td>
</tr>
</tbody>
</table>

From Table 2.2 about the knowledge requirements of the engineering graduates, it can be seen that the basic science, mathematics and engineering sciences are essential knowledge required in all the four accreditation criteria. The difference is that the EC2000 and IEAUST more
emphasize “the ability to apply” the knowledge. In UK SPEC and EURACE an appreciation of multi-disciplinary context is emphasized while EC 2000 and IEAUST mention this point by emphasizing the communication ability in multidisciplinary teams.

The second half of this part, including economics, business and management, environment matters and ethics is regarded by EURACE as transferable skills; while the other three put it under the category of knowledge and understanding. The issues in this part are relatively new in the engineering profession and sometimes they constitute a challenge for the already busy curriculum (Heittman, 2005; Ruprecht, 2000). Ethics is an item which can be distinctly found in all the four accreditation standards. While the other issues, are mentioned definitely in some criteria while more generally in others (such as global or social context). One point to note is that both UK SPEC and EURACE put sustainable development in their criteria while others do not.

Table 2.3. Required Attributes in engineering graduates-skills.

<table>
<thead>
<tr>
<th>Categories</th>
<th>UK SPEC 2004</th>
<th>EURACE 2005</th>
<th>ABET EC 2000</th>
<th>IEAUST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>communication</td>
<td>use diverse methods to communicate effectively</td>
<td>Communicate effectively</td>
<td>communicate effectively not only with engineers but also with the community at large</td>
</tr>
<tr>
<td>Interpersonal</td>
<td>working with others</td>
<td>function effectively as an individual and as a member of a team</td>
<td>an ability to function on multi-disciplinary teams</td>
<td>ability to function effectively as an individual and in multi-cultural teams, with the capacity to be a leader or manager as well as an effective team member</td>
</tr>
<tr>
<td>Team working</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2.3. Required Attributes in engineering graduates-skills (continued).

<table>
<thead>
<tr>
<th>Categories</th>
<th>UK SPEC 2004</th>
<th>EURACE 2005</th>
<th>ABET EC 2000</th>
<th>IEAUST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning how to learn</td>
<td>planning</td>
<td>recognize the need for, and have the</td>
<td>recognition of the need for, and an</td>
<td>Expectation and capacity to undertake lifelong learning</td>
</tr>
<tr>
<td></td>
<td>self-learning</td>
<td>ability to engage in independent,</td>
<td>ability to engage in life-long learning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Life long learning/CPD</td>
<td>Life –long learning.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem solving</td>
<td>problem solving</td>
<td>the ability to combine theory and</td>
<td>an ability to identify, formulate, and</td>
<td>ability to undertake problem identification, formulation and solution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>practice to solve engineering problems.</td>
<td>solve engineering problems</td>
<td></td>
</tr>
<tr>
<td>Design</td>
<td>synthesis/design ability-creativity &amp; innovation</td>
<td>engineering design</td>
<td>an ability to design a system,</td>
<td>Ability to utilize a systems approach to design and operational performance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>component, or process to meet desired</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>needs</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>analysis ability; practical skills; effective use of general IT facilities and information retrieval skills</td>
<td>engineering analysis; engineering practice; investigations</td>
<td>an ability to design and conduct experiments, as well as to analyze and interpret data; an ability to use the techniques, skills and modern engineering tools necessary for engineering practice</td>
<td>understanding of the principles of sustainable design and development</td>
</tr>
</tbody>
</table>

In Table 2.3 it can be seen that the four criteria share similar opinions on what skills should be required of the engineering graduates with some minor differences. The communication ability, team working, interpersonal ability, lifelong learning and problem solving skills, which

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*Literature Review*
generally are regarded as “transferable skills”, can be found in all the four criteria. The ability of self-learning or independent learning is particularly mentioned in UK SPEC and EURACE while the capacity to be a leader or manager is specially emphasized in EURACE. In the following part, the design and analysis ability are required with innovation and creativity ability expected (UK SPEC). Also practical skills are particularly emphasized in UK SPEC and EURACE together with modern tools to be able to be used in practice.

2.2.2 Current Pedagogical Trends in Engineering Education

It can be seen from the accreditation criteria in different countries that both the “hard” science knowledge including the basic science and mathematics and the “soft” skills or competence such as communication skills, teamwork, lifelong learning etc. are required of potential engineers, with the latter being more called for by many industries. In addition, the imperatives of environmental protection and sustainable development make it urgent for the potential engineers to develop an awareness of sustainability, economics, business management and ethics, etc. How to add these to the already packed engineering curricula and how to teach all these knowledge to the undergraduates effectively within their limited time at university? Traditional instructional methods have repeatedly proved inadequate to meet the challenge (Grose, 2006).

Heitmann (2005) argued that the acquisition of the kind of competence or skills does not necessarily require the introduction of new courses, but should normally be an integrated part of teaching and learning approaches in certain subject areas. He suggested that project-organized curriculum and problem-based learning should be used to satisfy the demands for the required knowledge, skills and attitudes of engineering graduates, even with regard to research profile of programs. And he proposed

“a guiding principle should be that students right from the beginning of their studies should learn and work in teams and on projects, trying to solve more or less complex, open-ended, often interdisciplinary real life or research problems.” ... “The project work should cover most of the activities of the students ...and only a few project-independent
course of the traditional type like, eg: in parts of mathematics.”

The role of project-based learning in engineering education was studied as early as 1970s Schachterle and Viniter (1996) and was summarized by Schachterle and Viniter (1996) as shown in Figure 2.1 below:

[Diagram illustrating the role of projects in engineering education]

The distribution of the universities currently adopting project-organized curriculum worldwide was summarized based on papers by Arne (2000), Bridges (2007), Crosthwaite et al. (2006), Dym (1994), Heitmann (1996), Kerns et al. (2005), Lennox (2003), Millis and Treagust (2003), as shown in Figure 2.2 below:
It can be seen that in Europe, many universities have the tradition of applying project-based learning, such as the well-known Aalborg University in Denmark. In addition, the universities in some European countries are more or less under the influence of German model or “continental” tradition, which tries to fix a balance between schools and the industry.

In the US, from the 1990s, many efforts have also been made to apply project-based learning under the influence of ABET and to meet the industrial requirements.

Australian universities are a new force in applying project-based learning mostly in the reforms of the engineering curriculum. Besides project-organized curricula, there are also many Australian universities adopting problem-based learning in their engineering education.

Figure 2.2. Distribution of universities currently adopting project-organized curriculum worldwide.
2.3 ENGINEERING DESIGN EDUCATION

2.3.1 Definition of Engineering Design

Definitions of engineering abound, as do definitions of design.

UK SPEC 2004 defined design as: Design is the creation and development of an economically viable product, process or system to meet a defined need. It involves significant technical and intellectual challenges and can be used to integrate all engineering understanding, knowledge and skills to the Engineering solution of real problems.

ABET 2002 defined design as: Engineering design is the process of devising a system, component or process to meet desired need. It is a decision-making process (often iterative) in which the basic science, mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria synthesis, construction, testing and evaluation.

Armstrong (2002 from RAE) summarized three common elements in all designs:

✧ Need: all designs begin with a clearly defined need
✧ Vision: all designs arise from a creative response to that need
✧ Delivery: all designs result in a system or product that meets that need.

2.3.2. Nature of Engineering Design

There are generally two paradigms about the nature of engineering design.

From the perspective of cognitive psychology, design is regarded as ill-defined / ill-structured problem solving. Design is different from other forms of problem solving in that the structure of the (design) problem is usually not given and the criteria applied are at best only given abstractly, seldom in terms that can be directly applied (Dym, 1994; Eastman, 2001). The terms “ill-defined” and “ill-structured” were introduced to signify that design tasks required definition of the problem space and also the criteria applied to candidate solutions (Akin, 1986; Reitman 1964; Simon, 1973 from Eastman, 2001).
The ill-defined problem solving paradigm has been criticized by many groups who argued that designers are part of the situation in which they act and mentally construct their view of situation as well as the actions taken within it (Winograd and Flores, 1987 from Eastman, 2001). Some studies approached design from other paradigms rather than ill-defined problem-solving.

For example, some researchers have approached design as a social process, holding that designing requires the negotiation of interests and proposals of different participants; hence the process is social and knowledge socially constructed (Bucciarelli, 1994, 2001). In addition, many studies investigated the social role people play within design teams (Brereton et al., 1996; Cross and Cross, 1996).

Eastman (2001) argued that a central task of design is defining its context. His concept of context includes two aspects, one is external context which refers to the outer environment involving system, physical, social, cultural and environmental contexts; the other is design response which is the intervention made by the designer responding to the external context. He believed that “defining the context and the repertoire of materials and methods that make up the designed response are core issues in effective design.”

Likewise, Cross and Cross (1996) held that design is based on a contextual situatedness. Bucciarelli (2001) argued that design thought, knowledge and knowing is very much dependent upon context, and that context is social, for designing is generally a collaborative effort which engages individuals within (and outside) the firm. He argued that we need a more contextualized understanding of engineering knowledge and that this means we need to pay attention to the social character of engineering practice, in particular of engineering design.

2.3.3 The Role of Engineering Design in the Engineering Curriculum

2.3.3.1 Historical Background of the Role of Engineering Design

The proper balance between science, engineering science, and design is one of the issues engineers and engineering educators has debated at length over the last 125 years (Seely, 2005). In essence, this is a debate on the nature of engineering and the best preparation for professional

Hands-on apprenticeship is the original engineering educating means in very early time. The practical element was strong until roughly before the last half century. The reason, as Prados (1998) analyzed, is that new technological development at that time such as atomic energy, radar, etc. called for much stronger foundation in mathematics, basic science and engineering science than had been provided by most pre-war curricula.

In the US, immediately following the 1955 Grinter report, engineering curricula swung from an applied practice-oriented focus to a mathematical, academic, engineering science focus and hands-on engineering experiences were replaced with additional math, physics and science courses (Seely, 2005; Sheppard, 1997). Afterwards, engineering curricula have been based largely on the “engineering science” model over the last five decades, in which engineering is taught only after a solid basis in science and mathematics. The first two years of the curriculum are devoted primarily to the basics sciences, which served as the foundation for two years of “engineering science” or “analysis” where students apply scientific principles to technological problems (Dym et al., 2005).

The UK engineering education experienced a similar swing from practice focus to science focus, which can be seen in the Figure 2.3 below proposed by Harvey and Baldwin (1994) which shows the contrast of the skills and knowledge used by the 19th century engineers with that of the graduates from many of the present science dominated engineering courses:

![Diagram](image)

**Figure 2.3.** The comparison of design between past and present engineering curriculums.
In the course of this period, the problem of the lack of understanding of design caused by the “engineering science” model in engineering curricula was noticed by engineering educators and measures were taken. For example, in the UK, a series of official documents including Moulton Report (1976), Finniston Report (1980) and Grant Report (1985) were issued requiring that

_Engineering should be taught in the context of design, so that design is a continuous thread running through the teaching of undergraduate engineering. Courses should expose the student to a proper mixture of analysis, synthesis, conceptual design and other wider issues. (Moulton Report, 1976)_

Similarly, around the same time, US engineering educators produced several studies, one of which was a recommendation to incorporate design throughout the four year curriculum (Sheppard, 1997).

However, in the US, by the middle 1980’s, increased pressure to include more technology in the curriculum, particularly computer-related technology, squeezed already packed curricula and design element was decreased accordingly (Sheppard, 1997). In the UK, a survey and review on the engineering design education on undergraduate degree courses in the UK universities and polytechnics by the Fellowship of Engineering (the original name for the Royal Academy of Engineering) in 1991 also showed some problems in the engineering design education including the varying extent of design inclusion, small number of dedicated design teachers, heavy teaching load and little time for personal research, etc (Black, 1991). Even today, studies showed that design faculty still feel that the leaders of engineering departments and schools are unable or unwilling to recognize the intellectual complexities and resources demanded to support good design education (Todd et al., 2004).

2.3.3.2. Current Development of Engineering Design in Engineering Education

In the US, since the late 1980s, there has been a national movement to increase the amount of exposure undergraduate students to engineering design. This has been particularly true at the freshman level (Sheppard, 1997; Dym, 2005). Sheppard (1997) summarized some key reasons...
for the movement, two of which are also applicable worldwide:

First, the development of educational theory

Design education, when based on open-ended problem-solving and authentic projects, is consistent with current thinking about learning in the school of Constructivism which holds that knowledge is constructed from experience. In Constructivism, learning results from a personal interpretation, is active with meaning developed on the basis of experience, is collaborative with meaning negotiated from multiple perspectives and should be situated in realistic contexts. In addition, testing should be integrated with the task. There is an increasing collaboration of engineering professoriate with cognitive scientists in a meaningful way to create effective learning and teaching environment and experiences (Newstetter et al., 2001; Sheppard, 1997).

Second, the design requirements of new accreditation criteria

Almost all the new accreditation criteria emphasize the importance of design competence in engineering graduates. In the US, an increasing awareness that engineering curricula often lack a sufficient design component has led to ABET’s increased emphasis on design, and the ABET design requirements provide the common thread that links capstone design courses for all engineering disciplines (Dutson, 1997; Dym, 2005). In the UK, design is a continuous emphasis by the accreditation body of the professional institutions since 1980s. The UK SPEC 2004 took form of outcomes-based standards, like the US’ ABET and Australia’s accreditation criteria, to emphasize what outcomes are expected of graduate engineers. Generally, it is the institution’s responsibility to articulate the goals of its program, the logic used in the selection of engineering topic to meet the goals and identify the major, meaningful design experiences and how they are integrated throughout the curriculum (QAA, 2006; Sheppard, 1997).

At present, design is widely considered to be a central activity of engineering (Dym, 2005; Simon, 1996), and it has been recommended that engineering should be taught in the context of design (RAE, 2005). Many educators argued that, ideally, design should be used as a means of integrating all parts of the engineering study program (Vernon, 2000).
2.3.4. Engineering Design Projects

2.3.4.1. What Makes Engineering Design Difficult to Teach?

Problem solving and design are the heart and core of engineering, but how we learn those skills is still a question not yet answered (Grose, 2006). The reasons for the difficulty in design teaching can be generalized from two aspects:

First, from the aspect of the complex nature of design itself

Cross (2004) made an overview of the research on the expertise in design between novice and expert designers, and argued that in design education, “there is still precious little real understanding of the differences between novice and expert performance in design, and how to help students move from one to the other.” Therefore, “we still need a much better understanding of what constitutes expertise in design, and how we might assist novice students to gain that expertise”. And he further argued that one of the research focuses should be to find out if certain educational methods assist the transition more effectively or efficiently.

Dym et al. (2005) analyzed the reason why design is hard to learn and even harder to teach from the perspective of design thinking. They argued that design process is itself a complex cognitive process, and that design thinking relates to how designers think and learn, which is an important reason that design is difficult to teach. There are many informative approaches to characterizing design thinking, and those characterizations highlighting the skills often associated with good designers include the ability to:

- Tolerate ambiguity that shows up in viewing design as inquiry or as an iterative loop of divergent-convergent thinking;
- Maintain sight of the big picture by including systems thinking and systems design;
- Handle uncertainty;
- Make decisions;
- Think as part of a team in a social process; and
- Think and communicate in the several language of design.
These characterizations were listed in more detail by Sheppard and Jenison (1997), which are, to a great extent, comparable with the requirements of the accreditation criteria, as shown in Figure 2.4 below:

| 1. Communicate, negotiate, persuade |
| 2. Work effectively in a team |
| 3. Engage in self-evaluation and reflection |
| 4. Utilize graphical and visual representations and thinking |
| 5. Exercise creative and intuitive instincts |
| 6. Find information and use a variety of resources |
| 7. Identify critical technology & approaches, stay abreast of change in professional practice |
| 8. Use analysis in support of synthesis |
| 9. Appropriately model the physical world with mathematics |
| 10. Consider economic, social and environmental aspects of a problem |
| 11. Think with a systems orientation |
| 12. Define and formulate an open-ended and/or under-defined problem, including specifications |
| 13. Generate and evaluate alternative solutions |
| 14. Use a systematic, modern, step-by-step problem solving approach. Recognize the need for and implement iteration |
| 15. Build up real hardware to prototype ideas |
| 16. Trouble-shoot and test hardware |

Figure 2.4. Qualities expected of a design engineer ---adapted from Sheppard & Jenison, 1997.

Second, from the aspect of the nature of design projects

The typical design project does not seek a single correct answer; there are usually many acceptable design solutions to a design problem, so uniqueness does not apply (Dym, 1994). The student is invited to make propositions which are often speculative and exploratory in nature. The students’ responses are likely to be unique and individualistic and may owe more to subjective, tentative and exploratory interpretation and intuition than to a logical and formulaic process and the application of a rational body of knowledge (Schön, 1983). In many cases the response to the brief is the development of a further set of questions or issues that the students need to address. The learning process is therefore inherently iterative, nonlinear and unpredictable. In some cases the problems identified may never be resolved and thus the student design work remain open ended and uncertain. The design project is not about solving problems,
but rather is about making propositions, refining and, to some extent, testing them (Roberts, 2004).

2.3.4.2. Variety of Engineering Design Teaching and Learning

RAE (2005) summarized the variety of design projects and their implementation. Design projects can tackle a simulated or real task, be undertaken individually or by a team, be paper-based or involve building and testing a model or prototype, and can focus on one discipline or be multi-disciplinary. Simulated design projects are frequently used during the first two years as the teaching and the resources can be carefully planned and matched to a specific aspect of the design process and to the knowledge of the students. In the final two years of a course, when the students have developed design and analysis skills and built up sufficient technological repertoire, real projects can be tackled, often in collaboration with industry or a university research project.

Dutson et al. (1997) reviewed the teaching of project-oriented capstone courses in the U.S. through a literature search over 100 papers relating to engineering design courses. Their review showed great variety in the capstone design project teaching in the respect of course content, project type and sources, faculty and industry involvement, features of students’ team and finally, the evaluation of the design project courses.

Similar variety also exists in freshman design courses, or cornerstone courses. The freshman design courses are similar to many senior design courses, but differ markedly in their tendency to focus more heavily on conceptual design methods and less on discipline-specific artifacts (Dym et al., 2005).

For example, Sheppard and Jenison (1997) summarized an organizational framework for freshman design courses including the following quadrants: A) individual-content centric (most traditional lecture-based courses); B) Tem-content centric (many traditional lab-based courses); C) Individual-process centric (many studio art courses) D) Team-process centric (most senior-level capstone courses) They argued that ideally a student’s four years in an engineering
program would contain design courses in each of the quadrants.

Table 2.4 below summarizes the existing varieties adapted from Dutson et al. (1997) and other related research papers (Dym, 1994; Little and Cardenas, 2001; Oaks et al., 2000; Pimmel, 2001; Sheppard, 1997; Thigpen et al., 2004):

<table>
<thead>
<tr>
<th>Variety categories</th>
<th>Types of design projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project sources</td>
<td>hypothetical projects / industrial projects /non-profit client or service</td>
</tr>
<tr>
<td></td>
<td>learning projects / students’ own projects / university’s projects / project competitions</td>
</tr>
<tr>
<td>Project length</td>
<td>From one quarter of a semester to two semesters</td>
</tr>
<tr>
<td>Design phases &amp; complexity</td>
<td>conceptual design / detail design /total design /integrated design/</td>
</tr>
<tr>
<td></td>
<td>multidisciplinary design</td>
</tr>
<tr>
<td>Design environments</td>
<td>lab /design studio/inside/outside classroom</td>
</tr>
<tr>
<td>Ways of teaching design</td>
<td>different proportion with lectures, problems, tutorials</td>
</tr>
<tr>
<td>projects</td>
<td>different ways of team formation</td>
</tr>
<tr>
<td></td>
<td>different ways of intervention</td>
</tr>
<tr>
<td></td>
<td>different involvement of technology, eg: multi media; simulation software, etc.</td>
</tr>
<tr>
<td></td>
<td>different involvement of teaching staff and industrial professionals</td>
</tr>
<tr>
<td></td>
<td>different ways of assessment</td>
</tr>
<tr>
<td></td>
<td>different combination with other disciplines, eg: technical writing</td>
</tr>
<tr>
<td></td>
<td>(Northwestern University), graphics (Penn State University and Iowa State University),</td>
</tr>
<tr>
<td></td>
<td>statics and strength of materials courses (University of Maryland and North Carolina State</td>
</tr>
<tr>
<td></td>
<td>University), short design exercises such as Delta Design in a laboratory section in</td>
</tr>
<tr>
<td></td>
<td>parallel with the more traditional strength of materials lectures (Stanford University)</td>
</tr>
</tbody>
</table>
2.3.4.3. **The Effectiveness Issue of Design Projects in Teaching and Learning Process**

Design projects are universally believed to be a vehicle to motivate and integrate learning by providing students with the hands-on, practical opportunity. First year design projects are also seen as a means to enhance students’ motivation and their retention in engineering (Dym et al., 2005). In addition, project-based design teaching reflects the ideas of current learning theories such as Kolb’s experiential learning cycles and cognitive psychology such as constructivism (Prince and Felder, 2006; Eastman, 2001), and thus has the potential to develop students’ knowledge and skills in a way that traditional approach fails to do, such as the deep learning of knowledge, transferable skills, development of different learning styles, etc. As can be seen in the pervious session, however, the effectiveness of project/problem-based learning is yet to be testified.

About the evaluation of the capstone design courses, most benefits fall into following two categories (RAE, 2005):

1) Engineering and Design knowledge:

*Enhance understanding of engineering;*

*Increase their technical repertoire;*

*Appreciate the integration of design and analysis;*

*Appreciate the importance of professional responsibility*

2) Transferable skills

*Learn how to work in multi-disciplinary teams*

*Develop leadership, management and communication skills;*

*Become motivated towards their engineering studies.*

Similar findings can be found in individual case studies. For example, Schultz and Christensen (2004) replaced the ways of teaching in interaction design courses traditionally taught by lectures and exercises in the first half of the semester and then project work in the second half of the semester. They applied an adapted seven-step problem-based learning procedure proposed

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by Schmidt (1983) together with short active learning lectures and found that students achieved developments in the aspects of responsibility for their own learning, inter-personal and intra-personal design teamwork skills and a deep approach to learning.

Dutson et al. (1997) found that the literature is filled with positive comments from students, instructors and industrial sponsors who have been participated in capstone design courses, and that the vast majority of participants feel that the course benefits all involved. However, one problem in the design project research is that the nature of design courses often leads to a purely subjective evaluation with little or no “hard evidence” of actual benefits (Dutson et al., 1997). This is a challenge in the research of the effectiveness of design project teaching and learning.

In addition, despite the effective learning outcomes of design project teaching, they are not without problems. In the design project learning process, students often have difficulties in cognitive aspect and transferable skills aspect (Dym et al., 2005; Emkin, 1995).

These problems can be found more frequently in the freshman design project teaching, where the results included both positive and negative aspects.

Schmidt et al. (1999) made an assessment of the effectiveness of a project-driven introductory level freshman design course. The course used a five-design cycle in the teaching process, that is, the five projects were used on a repeated cyclical basis. Three highest scores indicating the best learning outcomes were found: 1) knowledge of engineering principles and practice; 2) ability to function effectively as part of a team; and 3) ability to design a system, component or process to meet desired need. (These outcomes are measured based on the ABET 2000 criteria)

However, in Edward’s (2004) evaluation of three case studies of the use of design activities in the first and second years of engineering courses, he found that general student response was favorable, but a minority of students expressed a preference for conventionally taught approach. The author suggested that design and problem-based approach can be employed to advantage in early years, but intensive support and guidance are necessary to build students’ confidence and
to facilitate both subject and process skill learning.

Ernst et al. (2006) investigated the effects of three hands-on courses, model-analysis-driven textbook design projects, dissection projects and service learning projects, on the development of first year student design process knowledge. They used a pre-post course evaluation and results showed no differences between the three course models.

Okudan et al. (2006) further investigated the appropriateness of industrial based design projects in first year students and found that the lack of relatedness of design project to the engineering disciplines choice for the students lead to the worst experience of the students; also domain of the task may favor one gender or the other. Beneficial effects of higher tolerance for ambiguity are evident.

2.3.4.4 The Effective Ways of Implementation in Design Project Teaching and Learning

In the engineering field, what are the best ways to teach engineering and how effective they are is still an issue (Prism, 2006).

To overcome the difficulties and challenges of design project teaching and learning, some researchers and educators tried to improve its effectiveness by establishing a good framework for design project teaching and learning.

For example, Marin et al. (1999) analyzed the elements of an optimal capstone design project experience through a framework they developed including three areas: preparation, administration and execution, and assessment. They used departmental capstone survey to evaluate the course and found that the team ownership of a project, inspired by appropriate mentorship, is the most significant factor in providing students an optimal experience. Other key factors include selecting projects the students feel are important to the client and providing students the opportunity to meet with the client. The factors they identified fall into the category: student control/ownership in their learning and the construction of authentic learning.
environment, which are essential elements of project-based learning. In this research, however, what developments students achieved in their learning was not studied.

Tucker and Rollo (2006) described their effort on establishing best-practice principles for the teaching of third-year and forth-year group designs through focusing on effective group structures and assemblage and fair assessment models. Their findings suggested that a successful andragogy for collaborative design project should include teaching collaborative team working skills and introduce into the curriculum project management techniques centered on research models of group formation. Students worked better collaboratively if they had a degree of control over teammate selection and the assessment of their work.

Griffin et al. (2003) further explored the impact of group size and duration of an industry-based capstone design projects on learning objectives for the student, value to industry sponsors, and faculty resources. Their findings suggested that, at the same difficulty level, the one-semester offering was preferred by both students and industry sponsors and required fewer resources; students preferred smaller group sizes, while sponsors do not have a definitive preference; although technical analysis is significantly correlated with dollar value to the sponsor, technical writing skills and presentation skills were not.

Recent research has also focused on facilitation of the gradual development in students’ learning process in design project courses.

Aziz (2006) described a structured project-based learning in a senior Digital Design course. In contrast with open-ended projects used from the start, the structured approach uses very simple self-learning early projects by step-by-step project guides. The traditional weekly lecture format was avoided. Instead, students completed a number projects in the first half of semester before they attend a week of lectures. This way is to put more emphasis on the project-based learning approach and to promote self-learning. Subsequent projects have progressively increasing levels of complexity and engage students with a much deeper level of learning and problem-solving. He argued that this approach was suitable for the students with diverse background in terms of

*Literature Review*
their prior knowledge and skills.

Patrick and Mary (2001) described a similar effort in an introductory design course through the implementation of three projects different in difficulty and duration in a studio environment: design exercises providing a basis for learning design tools, a dissection project and a main design project for an external client. The course also engaged in some mini-lectures on group dynamics and conflict management, and project management tools, and class discussions evaluating student work or role-playing in ethics. Their findings are generally positive.

Similarly, Raucent (2004) described two types of projects implemented in their engineering curriculum: result-oriented project which is to apply and synthesize knowledge acquired, and learning oriented project, called pre-project, which focuses on the acquisition of new knowledge and competencies. Such projects come before (or simultaneously with) the courses and are used to contextualize the concept. They argue that the two types of projects have different but complementary domains of application, and the pre-project may best find its place of application in the first year of an engineering curriculum.

Emami (2005) adopted a hybrid framework which allows a gradual transmission from content-based to project-based approach in a sophomore multidisciplinary design course. The constituents of the course include: design projects, design lectures, technical lectures, tutorials and preparatory assignments. The author observed students’ strong enthusiasm towards the course despite the heavy workload.

In contrast, however, Ehrlenspiel et al. (1997) recommended an approach in the systematic design which they considered to be essential in students’ learning: to work on problems first without and then with supervisions- and the comparison between the two processes by students themselves.

The variety of the implementation of design projects indicates that researchers and practitioners are actively exploring ways how to effectively implement the design project teaching. Also it
reflects the current concern in the engineering education field about improving our understanding of what is the best way to teach engineering (Grose, 2006).

Examining the above design project research closely, however, it can be found that most research has the problem as what was described by Eastman et al. (2001, p2): “Few of the reports conducted rigorous evaluations of learning which would have indicated whether the intervention have been successful, and that the suggested pedagogical strategies did not demonstrate grounding in the research conducted over the last two decades in cognitive science and educational psychology”. The problem is partly due to the fact that in the design project context, most of students’ learning is hidden behind the teamwork, which is hard for teachers to effectively facilitate, and even harder to evaluate. Thus, how to effectively facilitate students’ learning in the context of design projects and how to evaluate the effectiveness of the facilitation is a great challenge in engineering design education.

When discussing the different ways of teaching in higher education, Prosser and Trigwell (1999) also argued that “while this type of variation has been the focus of much student learning research in the last decade, similar research on teaching has been given little consideration in the improvement of both learning and teaching despite the fact that it would appear to have profound implications for that practice”.

Against the background of the global debate about the effectiveness of project/problem-based learning in higher education and the fact that project-based learning is a most favorable approach in the engineering design education field, how to effectively implement this approach and how to evaluate its effectiveness in the design project context is still a question unanswered.

2.4 CONCLUSIONS
A thorough literature review was made on project-based learning, engineering education, and engineering design respectively. In project-based learning, great attention was paid to its features, particularly to the features different from those of other similar constructivist approaches. Problems were found in the current PBL research in the aspect of chaotic
implementations, flawed research methods and complex learning process in engineering education as well as engineering design. Measurement of PBL effectiveness with rigorous research methodology is called for; as well as improved PBL implementation.
Chapter 3.

RESEARCH METHODOLOGY

With the problems of PBL effectiveness in engineering design having been identified in the literature review, the proper research methodology needs to be considered to settle these problems. The choosing of rigorous and scientific research methods should be based on a thorough understanding of the relevant theories and the clear awareness of the advantages and drawbacks of those research methods having been applied in the research on PBL.

3.1 RESEARCH METHODS AND PHILOSOPHIES OF EDUCATIONAL RESEARCH

3.1.1. The Philosophical Issues of Educational Research

The nature of truth and the means by which it can be ascertained are controversial issues which have continuously evoked debates from ancient times to the present day. It is relevant to two philosophical issues in educational research: ontology and epistemology. Ontology is about “what we study” which is the object of investigation, while epistemology is about “how we know things”, which is “a branch of philosophy that addresses the question of the ‘nature, sources and limits of knowledge’” (Porta and Keating, 2008, p22).

In social science, Porta and Keating (2008) identified four broad approaches of ontology and epistemology which are positioned on a spectrum from most positivistic to the most humanistic. They are: 1) Positivist; 2) Post-positivist; 3) Interpretivist; 4) Humanistic. Similarly, in educational research, Carr identified two dominating yet distinctive philosophical traditions: empirical enquires, which defines research as “the systematic, controlled, empirical and critical investigation of hypothetical propositions about the presumed relationships among natural phenomena”, and the phenomenology of mind, which is about the understandings and perceptions of the subjects of research (Carr, 1995, from Pring, 2000, p31; Cohen and Mannion, 2007).
Beyond these, there are some other philosophical positions including ethno-methodology, ethnography, constructivism, post modernism and so on. These competing positions provide cultural and theoretical background for the research to be conducted and the methodology adopted (Lichtman, 2006; Porta and Keating, 2008; Pring, 2000).

3.1.2 The Relation between Research Methods and Philosophies in Educational Research

A potential problem brought forth by the philosophical categories as mentioned above in both social science research and educational research is that the difference between these categories is sometimes presented as a contrast between quantitative and qualitative methods, which is what Dewey referred to as “false dualism”, that is, a distinction made not based on appropriateness to task but on epistemology and ontology (Pring, 2000).

Porta and Keating (2008) argued that a distinction made between quantitative and qualitative methods according to epistemology is a great simplification, and may cause considerable confusion because positivists may make use of interviews, case studies and even participation observations, and interpretivists sometimes use quantitative techniques such as sophisticated computer software (Porta and Keating, 2008). Johnson and Onwuegbuzie (2004) also pointed out that “differences in epistemological belief … should not prevent a qualitative researcher from utilizing data collection methods more typically associated with quantitative research, and vise versa”.

Accordingly, some researchers put forward the approach of “mixed methods research” which combines elements from both quantitative and qualitative research (Creswell, 2003; Greene, Caracelli and Graham, 1989; Johnson and Christensen, 2004; Johnson and Onwuegbuzie, 2004; Tashakkori and Teddlie, 2003). The essence of mixed methods research is that “research methods should follow research questions in a way that offers the best chance to obtain answers (Johnson and Onwuegbuzie, 2004). Thus, they proposed a mixed methods research process model with the following eight steps: 1) determine the research question; 2) determine whether a mixed design is appropriate; 3) select the mixed methods or mixed-model research design; 4)
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3.1.3 Variety of educational research

3.1.3.1 Approaches in Quantitative Research

Quantitative methods typically include scientific modeling and experimenting, which “aims at singling out causal explanation, on the assumption of a causal-effect relationship between variables. Researchers aim at an explanation that is structural and context-free, allowing generalization and the discovery of the universal law of behaviour.” (Porta and Keating, 2008).

There are two ways in the causal explanation process: inductive approach and deductive approach. The deductive approach starts from “a theoretical hypothesis about the processes that brought it about”, and it moves from the general to the specific; on the contrary, the inductive approach moves from the specific to the general. It derives from “an empirical investigation of the phenomenon of interest” (Hertier, 2008, from Porta and Keating, 2008). In the deductive modeling, Hertier (2008) advised that the focus should be put on the model itself, instead of the one-to-one reflection of reality, and on the most important aspects of the situation, instead of minute description of a situation in reality.

3.1.3.2 Approaches in Qualitative Research

Qualitative research is the kind that aims at “understanding events by discovering the meanings human beings attribute to their behaviour and the external world (Porta and Keating, 2008).

Qualitative research typically includes phenomenological approach, which is to study the lived experience of individuals with the primary goal of describing the experience; anthropological and ethnographical approach, which are to study a socio-cultural phenomenon and how humans interact within a culture or subculture; case study, which is to study in-depth a particular event or setting or on particular people; grounded theory, which is to generate theory that is grounded in or emerges from the field; feminist theory, which is to use a feminist perspective in conducting research, and generic approach, which is to use qualitative methodologies to collect.
and analyze data. (Lichtman, 2006)

3.1.3.3 Data Collection Methods in Educational Research

Pring (2000) summarized a range of approaches that can be adopted in educational research. These approaches can be found to be used as data collection methods both in quantitative research and qualitative research of education, including 1) Observing what happens; 2) Experimenting; 3) Surveying what is the case; 4) Interviewing; 5) Case studying. Besides the above, focus group data collection is also increasingly adopted in educational research in the last two decades (Lichtman, 2006).

3.2 METHODS FOR MEASURING TEACHING AND LEARNING EFFECTIVENESS IN EDUCATIONAL RESEARCH

There are mainly two forms of educational evaluation: summative evaluation and formative evaluation (George and Cowan, 1999). The former emphasizes the end results and the latter the process. From the perspectives of learners, there are self-evaluation/assessment and peer evaluation/assessment (George and Cowan, 1999).

In a review of teaching effectiveness research of the last decade, Seidel and Shavelson (2007) summarized two main approaches to the research of teaching effectiveness: one is large-scale surveys with sophisticated statistical models which aimed to monitor student competencies and instructional practice; the other is quasi-experimental and experimental studies of the effects of specific instructional approach on students’ learning on various multidimensional aspects including cognitive, affective and meta-cognitive outcomes.

George and Cowan (1999) introduced three approaches to educational evaluation: The most commonly used approach to educational evaluation is to produce “quantitative records of such items as teachers’ efficiency and effectiveness, and learners’ progress”. This approach typically includes pre-post testing, drop-out rate or attendance. An alternative approach is to identify “all the effects of the course provision, and relate these to the rationally justifiable needs of the learners”. It includes “open-ended questionnaires, unstructured interviews and record keeping”.

Research Methodology
The third approach is what they called “illuminative” approach which is to identify a broad view of a range of expectations and processes, and of ways in which the programme is seen and judged, including its unexpected outcomes.

Besides the above approaches, meta-analysis as a quantitative research method is also found to be frequently used in analyzing the research on the teaching and learning effectiveness (Seidel and Shavelson, 2007; Strobel and van Barneveld, 2009).

3.3 METHODOLOGY IN RESEARCH ON PROJECT-BASED LEARNING

3.3.1 A Brief Review of the Development of Research Methodology in Project-based Learning

With PBL becoming well-established and widely recognized, the research issues and research methodologies have also developed.

In the beginning stage of the PBL development, especially during the 1970s, the methodology mainly belongs to descriptive, normative and conceptual research, as found in the research by Neufeld and Barrow (1976) and by Barrow and Tamblyn (1980) (from Du et al., 2009).

Since 1980s, with a growing number of studies being published in evaluating the effects of PBL and due to the nature of the research topics, the methodologies used in PBL become quite diverse, ranging from conceptual studies to empirical studies using both quantitative and qualitative methods (Du et al., 2009).

In the conceptual aspect, some descriptive models of PBL were proposed, including Barrow’s taxonomy of PBL (1985), Norman and Schmidt’s theoretical model (2000) and structural equation model (2000), Savin-Baden’s five PBL models (2006, 2007), and Kolmos et al.’s model for problem- and project-based alignment (2009). These models are increasingly comprehensive in identifying the various elements in a problem and project-based curriculum which determine the effective application of PBL.
The quantitative methods during this period include a few controlled experiments which compared the different effects between PBL and traditional teaching approach, such as the research done by Newman (2004); the qualitative methods during this period include some case studies or the ethnographic method, such as the research by Evensen et al. (2001).

Besides, Some researchers use quantitative meta-analysis to review the existing studies of PBL and analyze the different effects between PBL and traditional/conventional lecture-based teaching approach, including Albanese and Mitchell (1993), Vermon and Blake (1993) and Newman (2003). Recently Strobel and van Barveld (2009) used meta-synthesis, which refers to “a qualitative methodology that uses both qualitative and quantitative studies as data or units of analysis”.

3.3.2 The Debates about Methodology in the Research on Project-based Learning Effectiveness

Despite the increasing practice of PBL, the effectiveness of PBL vs traditional lecture-based teaching continues to be a controversial issue ever since PBL came into being. One controversial point focuses on the methodology adopted in measuring PBL effectiveness.

Norman (2004) criticized the lack of both methodological and conceptual clarity in the research of PBL. He supported the strengths of experimental approaches in educational research and is in favour of randomized experimental design in the research on PBL. Sanson-Fisher and Lynagh (2005) also found that the available evidence in the research of PBL effectiveness is methodologically flawed.

Mamede et al. (2006) denied the value of randomized experimental design in educational research and argued that it is based on wrong assumptions. On the other hand, they admitted the important role of experimental approaches in the PBL research, and added that other methodological approaches should also be used in order to “examine the several variables potentially acting in realistic settings and their complex interactions”.

Research Methodology
About the meta-analysis method used in the research on PBL effectiveness, Prince (2004) pointed out one potential pitfall that “aggregating the results of several studies on the effectiveness of PBL can be misleading if the forms of PBL vary significantly in each of the individual studies included in the meta-analysis”. His solution to this problem is to focus on the core element of active learning (including PBL). However, he also argued that PBL is difficult to analyze, compared with collaborative and cooperative learning approaches, because there is not one or two core elements that can be clearly identified with student learning outcomes.

3.4 THE METHODOLOGY IN THIS RESEARCH AND JUSTIFICATION

From the brief review of the research methodology used in PBL and the debates about it, the feature of current research methods application in PBL can be detected, that is, the role of quantitative methods and qualitative methods in PBL are positively recognized and applied, yet the tendency is either the former or the latter is emphasized and mainly adopted in reality. Few studies can be found which combined the two methods as one to settle issues in PBL.

From the study of the philosophical issues of educational research, it is known that ‘what to study’ (i.e. ontology) and ‘how to know things’ (i.e. epistemology) constitute the two issues of educational research. Likewise, the research on PBL effectiveness also includes two aspects: WHAT aspect and HOW aspect. It is not only necessary to know whether PBL is effective and what its effectiveness is, but also important to know how to implement PBL in a better, and even the best way. These two aspects are closely related and need to be taken into consideration at the same time in the research on PBL effectiveness.

Based on this principle, a mixed research method was adopted in the study of PBL effectiveness. In order to obtain quantitative findings, the initial assumptions of the research are proposed as follows:

1) The PBL effectiveness is measurable;
2) The PBL effectiveness is controlled by *infinite* parameters, including the observable and unobservable, the measurable and immeasurable, the controllable and uncontrollable, and histories.

In the Assumption 1), The PBL effectiveness, $E$, is a weighted combination of a set of assessments of effectiveness as follows

$$
E = \sum_{i=1}^{n_E} \left( w_i \times E_i \right) 
$$

where $E_i$ is one of the $n_E$ assessments of effectiveness, $w_i$ is weighted coefficients satisfying the condition

$$
\sum_{i=1}^{n_E} w_i = 1.
$$

The more number of the assessments, the more precise the PBL effectiveness is. In the present research a limit number of assessments are chosen for manifesting and verifying the modelling method. A wider assessment can be used in similar way in an extended model.

In the Assumption 2), the terminology, i.e. parameter and history, are defined as follows:

- **Parameter**: an entity which characterises the intrinsic behaviours and responses of students in PBL.
- **History**: an entity which records the affects and impacts accumulated as a consequence of the individual experiences.

A history can be considered as a *hidden* parameter which depends on particular individual experiences and environments. This hidden parameter has been changing with time and is uncontrollable by PBL. In contrast, a parameter can be considered history-independent. Therefore, a parameter can be either an uncontrollable entity keeping constant, e.g. IQ, or a controllable entity such as learner engagement.

Therefore, a model of PBL can be expressed generally as follows:

*Research Methodology*
where $E$ stands for PBL effectiveness, $P_1, P_2, \ldots, P_m$ are $m$ parameters, $H_1, H_2, \ldots, H_n$ are $n$ histories (hidden parameters). In a similar way, the sub-categories of PBL effectiveness can be modelled as

$$E_i = E_i(P_1, P_2, \ldots, P_m; H_1, H_2, \ldots, H_n) \quad \text{where} \quad i \in \{1, 2, \ldots, n\}. \quad (4)$$

The more number of parameters, the more precise the model is. However, the main purpose of the present research is to find out the most relevant parameter(s) for manifesting and verifying the method. Thus in the present research, firstly, two parameters are proposed and their individual effects on PBL effectiveness are studied thoroughly by presenting 2D models. Secondly, a 3D model is presented to show the relation between the two parameters. Thirdly, the effects of the histories are presented by studying the effects of previous industrial experiences on the PBL effectiveness. Together, the very general model in eqn. (1) can be presented and justified by using limit number of parameters and histories. Models with more number of parameters and histories can be presented in a similar way.

Meanwhile, in the qualitative aspect, studies were made to define PBL effectiveness from the perspectives of PBL teachers and engineering graduates via interviews to identify the categories of PBL effectiveness. In addition, an ethnographical approach was adopted to identify the dynamic interaction of the PBL learners’ individual differences via observation and interviews, which is a necessary supplement to the deeper understanding of PBL effectiveness.

### 3.5 CONCLUSIONS

In this chapter, a study of the research methods and philosophies of educational research was made in order to have a thorough understanding of the theories. The research methods in PBL were reviewed and debates about this issue were found. The research methodology in this thesis which combined quantitative and qualitative methods was described and justified. The subsequent chapters presented the details of how the methodology was applied to settle the issue of PBL effectiveness.
Chapter 4.

DEFINING EFFECTIVENESS OF PROJECT-BASED LEARNING IN ENGINEERING DESIGN

Research on the effectiveness issue in engineering education and in PBL is abundant. On the one hand, most of the effectiveness criteria of engineering education were made either from government documents, such as the UK SPEC (2004), or QAA Benchmark (2006), or from the industrial perspective, such as the Cox review (2005). On the other hand, the criteria of PBL effectiveness in engineering design were rare and generally based on the study of undergraduates (Duston, 1997; Shepard, 1997). To date, there has been little research on the effectiveness of PBL in engineering design from the perspectives of engineering lecturers or engineering graduates. This study, then, was to target these two groups of people and to define effectiveness of PBL in engineering design by taking their views into consideration.

4.1 EFFECTIVENESS OF PBL IN ENGINEERING DESIGN FROM THE PERSPECTIVE OF UNIVERSITY ENGINEERING DESIGN LECTURERS

4.1.1 Purpose of the Interview

In order to have an in-depth understanding of the design project module teachers’ ways of PBL implementation and their opinions on the nature of design and on the issue of effectiveness of design project teaching and learning, interviews were conducted with the teachers in charge of engineering design project modules.

4.1.2 The Design of the Interview

The interview included two broad parts:

The first section was structured, focusing on the following three sub-sections:

1) the information of the design project itself; including the type and source of the project(s), number of projects used, length of the project(s); starting time of the project(s), etc.
2) the information of staff and students, including number of staff involved, number of students, team size, the ways of and the reasons for the team formation
3) the information of the ways of teaching, focusing mainly on the ways of lecture, including the timing, proportion and effectiveness of lectures, the ways of tutorial and assessment.

The second section was semi-structured, focusing on the following two sub-sections:

1) teachers’ opinions on the effectiveness of their modules, including their stated learning
outcomes, difficulties in the teaching and in students’ learning, etc.,
2) teachers’ understanding of the nature of design, and design teaching and learning, including what is design and how to teach and learn design, etc.

4.1.3 Data collection
The interviews were carried out during the second academic semester of 2008, from February to May. Ten teachers from 4 engineering departments in Loughborough University and University of Leicester were interviewed. Among them, 8 teachers were in charge of design project modules during that semester, and 2 teachers were in charge of a design project module in previous semester (s). The details were shown in Table 4.1:

Table 4.1. Information of the interviewed lecturers.

<table>
<thead>
<tr>
<th>Department</th>
<th>Number of teachers</th>
<th>Academic year of the module</th>
<th>Duration</th>
<th>University</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeronautical &amp; Automotive engineering</td>
<td>2 Teacher A 2</td>
<td>2 One hour</td>
<td></td>
<td>Loughborough University</td>
</tr>
<tr>
<td></td>
<td>Teacher B 4</td>
<td></td>
<td>Half hour</td>
<td></td>
</tr>
<tr>
<td>Electric &amp; Electronic engineering</td>
<td>2 Teacher C 3</td>
<td>3 One hour</td>
<td></td>
<td>University</td>
</tr>
<tr>
<td></td>
<td>Teacher D 3</td>
<td></td>
<td>One hour</td>
<td></td>
</tr>
<tr>
<td>Civil and Building engineering</td>
<td>4 Teacher E 4</td>
<td>4 Half hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher F 3</td>
<td></td>
<td>One hour</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher G 2</td>
<td></td>
<td>One hour</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher H 1</td>
<td></td>
<td>One hour</td>
<td></td>
</tr>
<tr>
<td>Mechanical engineering</td>
<td>2 Teacher I 1&amp;2</td>
<td>1 One hour</td>
<td></td>
<td>University of Leicester</td>
</tr>
<tr>
<td></td>
<td>Teacher J 1 4</td>
<td></td>
<td>Half hour</td>
<td></td>
</tr>
</tbody>
</table>

4.1.4 Findings and Discussions
4.1.4.1 The Design Projects
A. The types of design project
It was found that in the design project modules from the 1st year to 4th year, the interviewed teachers generally adopted the projects with elements of both conceptual design, which emphasizes the design thinking, and detail design, which emphasizes the design analysis.

Further, two teachers (teacher A & teacher I) also included the manufacturing/make and product stage, one was by students themselves in the design module, the other by students from the previous year rather than the students who designed the projects in the module. Teacher I held that the make and product stage in his design module can “help students have a concrete understanding of what engineering is like and increase their interest as well”. Teacher A believed that let one group/year of students design the projects and the other group/year of students manufacture them can help students know more deeply the difference and connection
of the two stages in design, especially when the students find that there are problems, for example, in the drawings, in the projects designed by others.

The make and product stage is used depending on the nature of products. For the civil engineering, teacher H said, it is difficult for the students to build real buildings from what they have designed, whereas for the mechanical or electrical engineering, it is relatively easy for students to make and produce real artefacts from what they have designed.

B. The source of projects:
Most teachers derived the design projects by themselves, making the design problem fictional, but “realistic”, that is, there is no such specific problem in the real world, but the similar problem may occur. In year 4, the real design projects, that is, real and live from industry or society, were increasingly adopted, although there are also “slightly imagined” design projects used in the final year.

Teacher J in the interview mentioned the difficulty of the derivation of design problems for teachers, especially for the relatively new teachers. He believed that “the design problem should be challenging but should not be too demanding. A good design problem can be used for students in various years, who can design with different knowledge base, and thus with different extent of complexity and quality.”

C. The length and starting time of the projects
The design modules generally lasted two semesters. For the 1st and 2nd years, however, the design project can be a “long theme” in that the lecture or tutorial in the first semester provides the theoretical foundation for the hands-on design projects in the second semester. Generally, the design projects started late in the 1st and 2nd years (there are exceptions, for example, one 2nd year mechanical design project started from the beginning of the first semester). In the 3rd and 4th year, design projects generally started from the very beginning.

From the perspective of PBL, the traditional ways of project-based learning in engineering, that is, theory first and then practice, are still implemented. While most final year design projects are closer to the so called “pure PBL”, some final year (including 3rd and 4th year) design modules are still a little bit “traditional” in that there are lectures paralleling with the “hands-on” learning process.

4.1.4.2 Numbers of Staff and Students
A. Number of staff
Generally, there is more than one teacher involved in the supervising of design projects. There might also be tutorial assistants involved (1st & 2nd year), or guest lecturers from within and outside the university, or professional consultants (3rd & 4th year). In some modules, it was planned to add more lecturers to share the teaching work (one in civil engineering and one in aeronautical engineering in this interview). This reflected the increasingly demanding work for design project teachers, for the reason of the increase number of students on the one hand, and on the other hand, the pressures of research work on teachers.

B. team size

The total number of students in design project modules varies greatly, from 20–30 to about 150. There were also various team sizes, from pairs to 3 to 5–6 to 10 students in each group. The reasons for the team sizes also vary.

Too many students in the module might be one reason that influences the teachers’ team size decision. For example, teacher E in the interview believed that 3 or 4 students in each team is ideal to manage and for learners to learn and cooperate, but due to the too many students in the module, it is hard to realize and he had to use the team size of 5.

Some teachers decided the team size in their module based on the features of work in the projects. For the pair teams, for example, the two students in each group were required to do different yet related assignment, so they had to cooperate with each other; in the module with the team size of 10 students, there are totally 19 students who formed two teams and who could choose their preferred design project from two different ones. Thus, in this module, two teams of students did two different design projects.

Other teachers did not give specific reasons for the team size. But it seems that the amount of work involved in the project for each team might be a reason for teachers’ choice in the team size.

In summary, teachers’ decision on team size is under the influence of different factors, some of which are objective, for example, the number of students or the amount of work involved; others are subjective, based on teachers’ own preferences and own beliefs about the ideal team size.

4.1.4.3. Team Formation

Three ways of forming the design project teams were found, one is that teachers choose the groups, alphabetically or draw lots. This way is believed (teacher B & teacher F) to represent what happens in the real industry setting in which people generally do not have the chance to...
choose their group members. Also, it is believed (teacher A & teacher H) that this random way of choosing groups can avoid low motivation caused by otherwise familiarity among friends.

Another way is that teachers let the students choose the groups by themselves, and help when necessary. In this way, It was found (teacher C & teacher G) there are always a few students left without finding any group and need teachers’ help. It is not yet clear whether this may affect students’ motivation in doing the project, but one reason for teachers forming teams in this way is to avoid the likely conflicts due to the unfamiliarity between team members.

The third way is that the teacher chooses students with some prior design project experience and then asks the other students to choose one of these experienced students. Teacher I commented that this way can ensure the smoothness of the project process to a certain extent, with the leadership within the team.

**4.1.4.2. The Ways of Teaching**

A. Lecture

Lecture was found to be used by most teachers in the interview in their design project modules and is used to pave the way to the design projects. The amount of lecture depends on the types of projects. The design projects emphasizing detail design may involve more lectures for the students to understand the design analysis; while in the design projects emphasizing conceptual design the lectures are less.

In the final years (3rd & 4th year), some design modules have little lecture or no lecture at all; while a good amount of lecture still exists in some final-year design project modules (teacher F). Teacher B who was in charge of a 4th year design project module emphasized that lecture is important and helpful in supporting the final year students’ projects and should not be undervalued.

For the design modules with a good number of students, for example, over 100, the attendance of lecture (also in tutorial) can be a problem. Teacher G provides the reason that some students did not realize how much work they had to do and expected to get away with less work than they should do; and for some first and second year students, they cannot balance the study and social activity well. This point was also mentioned by teacher C who was in charge of a 4th year module, which it would be discussed further in later sections.

Another problem about lectures, mentioned by teacher A, is that sometimes the lecture is a little bit demanding because the time for lecture is limited and is not easy for students to understand so quickly and thus not easy for students to apply what they have learnt from the lecture.
effectively to their design projects in the short term. This is a problem of the balance between theory and practice. Teachers face the dilemma that in the “learning by doing” approach, students do not grasp enough deep solid knowledge to apply, which in turn affect the quality of the design project itself. This is also the core of the controversial issue of the effectiveness of PBL which argues whether it is effective for students to learn from practice first or to learn theories from being taught first.

B. Tutorials
In the interview two types of tutorials were encountered, in-class tutorials and out of class tutorials were used by the teachers. In the in-class tutorial, teachers, or tutor assistants, check the progress of students’ design projects, point out problems, answer questions and give guidance. This type of tutorial was found most in the 1st and 2nd year design modules. In the out-of-class tutorial, students are free to go to teachers’ office and ask questions, or communicate with teachers through emails. This type of tutorial was found across the 4 years of design project modules.

One problem in the tutorial, as in the lecture, is the attendance of students. It seems that teachers need to take measures to control some students in this aspect, e.g. Teacher B mentioned that he used web-PA to settle this problem; while in teacher G’s module, there is no requirement of registration for the lecture or tutorial, thus, the attendance cannot be ensured.

The other problem is the effectiveness of tutorial. Generally, in the tutorial, the teachers, or assistants, usually only facilitate students’ learning instead of telling students what to do or how to do it. This is especially true in the design project tutorial because due to the nature of design, there is no specific, perfect answer to a certain design problem. Then even if the teachers wanted to, they could not provide the best solution to the design problem. Teacher A said that what he had to do was “keep stressing that there is no single, good answer, and students should learn to choose among many choices.” Another problem was mentioned by teacher C who talked about his tutorial and found that some (poor) students asked too simple questions that they should know by themselves.

The two teachers’ comments on the tutorial problems reflected the two aspects of the teaching aims stated by Barrow, one is to develop students’ thinking or reasoning skills as they learn, including problem solving, meta-cognition, critical thinking; the other is to help students to become independent, self-directed learners, including learning to learn, learning management, etc. (from Savery, 1995) The two aims are interrelated with each other, and their interdependence is specially close and important in the PBL approach because although PBL is characteristic of problem-based, self-directed learning, teachers’ facilitating skills are still “the

*Defining effectiveness in Engineering Design*
major determinant of the quality and success” of PBL. To know how to develop students’ ability in these two aspects (two aims) effectively might help solve the tutorial problems encountered by the design project teachers.

C. Assessment
Various methods of assessment can be found in the design project modules in the interviewed teachers’ modules. The common ways are written reports and oral presentations. Peer review and web-PA are used in only some modules. Teacher C mentioned that they usually know who has done the most amount of work in the group, but they feel difficult to know exactly other individuals’ share of work. Thus they face the difficulty in project assessment, and “effective ways of assessment is urgently required” (teacher D).

It is known that effective assessment can facilitate students’ learning, yet to ensure effective assessment is difficult in PBL. For example, some teachers feel it difficult to assess the part of knowledge which they themselves are not familiar but which is used by students in their projects (teacher J). For PBL as a whole, this is still an area yet to be explored.

4.1.4.5 Effectiveness of Design Project Modules
A. Student learning outcomes
Among the teachers interviewed, different aspects were emphasized as the effective learning outcomes in their modules. These learning outcomes were described from two perspectives: one is measurable learning outcomes of the modules; the other is the learning outcomes as generically described by the teachers (as shown by upper case).

From the first perspective, it was found that in the design modules of the early years (1st and 2nd year), emphasis was generally put on the familiarity of design: students are expected to know the difference between design and analysis. They should learn that “design is a woolly process with no perfect or specific answer”, and students should “learn to choose an answer from among a lot of choices” (teacher B). Knowledge of design and teamwork were also emphasized (teacher I, teacher G and teacher H).

In the later years (3rd and 4th year), the ability to apply knowledge to settle real world problems is most emphasized (teacher B); and “the extent knowledge”, that is, the amount of knowledge which can be used to apply in real design at this stage is also regarded as important (teacher E).

In the second perspective, as to the effectiveness of the learning outcomes actually achieved in these teachers’ design modules, two general aspects can be found: one is DESIGN THINKING ABILITY and the other is TRANSFERABLE SKILLS. For example, some teachers believed
that in their modules students’ design thinking ability and creative ability were developed effectively (teacher B and teacher F); some think that students’ teamwork, communication and independent learning ability were developed well (teacher B and teacher C); together with the professional way of running and participating meetings (teacher B); some teachers believed that their design modules helped students have more confidence in undertaking the projects, and improved their ability to define problems, get information and developed their presentation skills as well (teacher E).

As to the aspects that teachers feel it difficult for the students to grasp, again varieties can be found among teachers. For example, teacher A found that “THE LATERAL THINKING” ABILITY, that is, the original, innovative ideas of solving problems, is very difficult for 2nd year students to develop because students are accustomed to following what is taught or learnt; TEAMWORK is another ability difficult for students to develop because students are generally educated in a spoon-fed way. Teacher B found that THE JOINT REPORT is difficult for the final year students to write because it is a cooperative job, “students have to do it together without separate share of work”, which is also a kind of team work. Teacher E found that THE ABILITY TO DEFINE DESIGN BRIEF is difficult in final year students’ eyes because of the ill-defined nature of the problem in the brief. Teacher C mentioned that “TRANSLATING IDEAS TO THE PRACTICAL” is difficult for many 3rd year students, which “partly depends on the students’ effort, partly on the design genius”.

In summary, from the teachers’ perspective, the effectiveness of design project modules was reflected in the following three aspects in the learning outcomes:

1) THE DESIGN ABILITY, including the knowledge of design process and the ability of design thinking (creative and critical thinking, or lateral thinking)
2) KNOWLEDGE APPLICATION ABILITY, about how to translate theory into practice.
3) TRANSFERABLE SKILLS, especially team work, including the joint report and running or participating meetings;

B. Differences in student ability

The difference in students’ ability in the design project modules and their reasons were talked about in the interview.

Teacher C found that the gap between the best and worst students was huge, and he believed that effort and interest were the main reasons: “The best students work harder and learn more; while the poor students do not devote much time; do not attend lectures. Instead, they enjoy social activities, and usually ask simple questions that they should know by themselves”. He
held that “if students lack knowledge, teachers can help; but if they lack interest, then teachers can do little to help them”.

Teacher G believed that students’ ignorance of the amount of work required of them might be the reasons for the poor students. He mentioned that some students “do not know how much hard work there is to do, and they think they can get away by doing less work than they should.” In addition, some (poor) students need to learn how to balance their study and social work. Similar opinions were held by teacher E, who believed that “how much students can work out what they are required to do” and “how well they work on a team” can result in different learning outcomes (good or poor) among the students.

From the teachers comments on the difference between good and poor students, it can be found that students’ ability to organize their own learning, or the ability to learn how to learn, is very important, including what to do, how much to do, when and how to do. It is part of the lifelong learning skills which need to be developed during their university time. Also the lifelong learning skills, here particularly refer to the right and effective ways of learning, might in turn improve students’ interest or motivation. Then improving students in this aspect might help improve poor students to a certain good level, and improve the good students to an even better level.

C. Nature of design & design teaching and learning

The nature of design is closely related with how to teach design. Some teachers believed that design teaching “is a matter of practice” (teacher A & teacher I). They held that students “can be trained to be creative, and learn how to think through practice”, which is hard to be learnt through lectures. While other teachers are more cautious and held that design process can be learnt by students (teacher E). Teacher G believed that teachers can teach students principles, but cannot teach them how to come up with ideas. Also, it is necessary to distinguish the difference between conceptual design and detail design when talking about the issue of how to teach design. The similar opinion was also held by teacher F, who estimated that maybe the former type of design more lends itself to the PBL approach, while the latter type might be better to be learned through lectures.

Here it seems that design teachers did not come to an agreement to use project-based learning to teach every part of design; at least, the amount of PBL might be different in different types of design modules, especially when it comes to the detail design, and when students are still in the early years.
4.1.5. Implications
A. Varieties in the design project teaching
Great varieties can be found in the design project teaching, which can be generalized into two main aspects:

First, teaching management, from the ways of forming teams and team sizes to the types of design problems and the different ways of dealing with lectures, tutorials and assessment.

Second, teachers’ understanding of effective design teaching and learning, including what to emphasize and how to teach it.

The varieties result partly from the nature of design, for example, the conceptual and detail design may call for different ways to teach it, partly from teachers’ teaching beliefs. Most, maybe all, teachers teach based on their personal experience and personal beliefs about teaching, for example, teachers’ beliefs about teaching design in projects (Dutson, 1997), or teachers’ decision on team sizes and teaching management, etc.

B. Common themes in the design project teaching
Beneath the varieties of the ways of design teaching and teachers’ understanding of design teaching, the topics teachers frequently mentioned are design thinking ability and team work ability, both of which are believed to be aims of effective design teaching and at the same time both are the difficult parts for students to grasp/develop.

In addition, about the good and poor students, it seems that students’ awareness of what is required and how much is required from them is important to influence their effort put into their learning. This self-awareness depends on their own exploration in their study and their self-directed learning ability.

4.1.6 Conclusions
Interviews were conducted among teachers who are in charge of design project modules. Great varieties were found in these teachers’ implementations of design project teaching. Reasons for the varieties were analyzed and common themes beneath these varieties were also discussed.
4.2 EFFECTIVENESS OF PBL IN ENGINEERING DESIGN FROM THE PERSPECTIVE OF ENGINEERING GRADUATES

4.2.1 The Aim of the Interview
This interview was targeted to the engineering graduates, including both the graduates whose work was relevant with engineering design and those whose work was irrelevant with engineering design. The reason for choosing these two groups of interviewees was, on one hand, to study what effects of the design projects at university had on these people at work, and on the other hand, to know if there were any different effects between these two groups of people.

The purpose of the interview is threefold: First, to find out what is learnt in the design projects at university from the perspective of engineering graduates; Second, to find out the usefulness/benefits of the design projects for the work taken by the engineering graduates; Third, to provide some suggestions for the learning in engineering design projects at university.

Thus, there are three main themes in the interview questions:
1. What was learnt from the engineering design projects at university?
2. How is the learning useful for the engineering graduates at work?
3. What needs to be improved for the design project learning at university?

4.2.2 Design of the Interview
4.2.2.1 Structure of the Interview
The interview was divided into four sections:
Section 1: Biographical information including the interviewees’ degree programmes at university, the year of graduation, final degree, industrial experience during university study, present occupation and the relevance of present occupation with engineering design

Section 2: Recall and reflection of the design project learning at university

Section 3: The usefulness of design projects at university for the present work

Section 4: Suggestions on improving the design projects teaching and learning at university

4.2.2.2 Participants
This interview was targeted to the engineering graduates, including both the graduates whose work was relevant to engineering design and those whose work was irrelevant to engineering design. The reasons for choosing these two groups of interviewees was, on the one hand, to
study what effects of the design projects at university had on these people when they are at work; on the other hand, to identify what differences of effects between these two groups of people.

### 4.2.3 Data Collection and Analysis

The interview was conducted from March to August of 2009. The way of contacting the interviewees was through the recommendations of engineering lecturers/professionals and the engineering liaison officer at engCETL (Engineering Centre for Excellence in Teaching and Learning). Totally six interviewees were interviewed, four of them were taking work which was non or loosely relevant with engineering design, and two of them were taking engineering design relevant work. The information of the interviewees was shown in Table 4.2:

#### Table 4.2. The information of the engineering graduate interviewees.

<table>
<thead>
<tr>
<th>Interviewees</th>
<th>Present work</th>
<th>Relevance with engineering design</th>
<th>Graduation year</th>
<th>Course program at university</th>
<th>Final degrees</th>
<th>Interview time length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Graduate engineer</td>
<td>Non</td>
<td>2008</td>
<td>Civil Engineering</td>
<td>MEng</td>
<td>40 minutes</td>
</tr>
<tr>
<td>B</td>
<td>Construction manager</td>
<td>Loosely</td>
<td>2008</td>
<td>Construction Management</td>
<td>MEng</td>
<td>42 minutes</td>
</tr>
<tr>
<td>C</td>
<td>Research engineer</td>
<td>Loosely</td>
<td>2006</td>
<td>Mechanical Engineering</td>
<td>MEng</td>
<td>67 minutes</td>
</tr>
<tr>
<td></td>
<td>Engineer</td>
<td>Loosely</td>
<td>2008</td>
<td>Mechanical Engineering</td>
<td>MEng</td>
<td>55 minutes</td>
</tr>
<tr>
<td>Group 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Section engineer</td>
<td>Closely</td>
<td>2006</td>
<td>Civil Engineering</td>
<td>MEng</td>
<td>online</td>
</tr>
<tr>
<td>E</td>
<td>Process engineer</td>
<td>Closely</td>
<td>2008</td>
<td>Chemical Engineering</td>
<td>MEng</td>
<td>online</td>
</tr>
</tbody>
</table>

### 4.2.4 Findings

#### 4.2.4.1 Information of Industrial Experience and Number of Group Design Projects at University

It was found from the interview that most of the graduates had work placement or industrial experience during their university study. The period lasted from several months to one year. All of them had group design projects during the university study, two of them had only one throughout their university study; two of them had two main ones at university, and two of them had at least one in each academic year. The details were shown in Table 4.3:
Table 4.3. Work placement or industrial experience and number of design projects at university.

<table>
<thead>
<tr>
<th>Interviewees</th>
<th>Work placement or industrial experience during university study</th>
<th>Number and length of group design projects during university study</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2~3 months in 2\textsuperscript{nd} &amp; 3\textsuperscript{rd} year each</td>
<td>At least one per year Main one in final year (individual &amp; group)</td>
</tr>
<tr>
<td>B</td>
<td>3 months in 1\textsuperscript{st} year, 2\textsuperscript{nd} year, 3\textsuperscript{rd} year each</td>
<td>3\textsuperscript{rd} year - 1 semester</td>
</tr>
<tr>
<td>C</td>
<td>1 year placement between 2\textsuperscript{nd} &amp; 3\textsuperscript{rd} year</td>
<td>Main one in 2\textsuperscript{nd} year and final year respectively</td>
</tr>
<tr>
<td>D</td>
<td>Summer work</td>
<td>1-2 per year</td>
</tr>
<tr>
<td>E</td>
<td>1 year placement</td>
<td>2\textsuperscript{nd} year (2 months); 4\textsuperscript{th} year (individual &amp; group; 6 months)</td>
</tr>
<tr>
<td>F</td>
<td>/</td>
<td>Main one in the final year</td>
</tr>
</tbody>
</table>

4.2.4.2 Learning from Engineering Design Projects at University

From the responses of the interviewees about their learning out of the design projects at university, three general learning categories were drawn out, which are understanding of engineering design, knowledge application and transferable skills. In each general category, there were further different dimensions, as shown in Table 4.4:

Table 4.4. Categories of learning from design projects at university.

<table>
<thead>
<tr>
<th>Engineering design</th>
<th>Knowledge application</th>
<th>Transferable skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>Reinforcement of old knowledge</td>
<td>Communication ability (oral &amp; written)</td>
</tr>
<tr>
<td>Design thinking</td>
<td>The relation between theory and practice</td>
<td>Sense of responsibility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leadership</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Learn from team mates/ teamwork skills</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Self-directed learning ability</td>
</tr>
</tbody>
</table>

A. Engineering design

a. Engineering design as technical

For the engineering students, One thing they learnt from doing design projects at university would be a fresh look at engineering design and a new understanding of it. Interviewee C described the changes of design understanding he experienced from doing design projects at university:

[Interviewee C]: “Initially my thoughts on design were very much geared towards the knowledge about product design, so at the early stage in my degree the design to me was how to make things look good, how to make it functioned. I think as I progressed through doing these design projects, it became apparent to me that as an engineer what matters in design was how to make things work: was it going to be reliable, was it going to be endurable, was it going to be accurate, you know, what materials to use, what specifications we should use, how we should use upon these things, how to make things assemble.”

It can been seen that for interviewee C, his change in design understanding was from looking at
it as product design to looking at it with the engineering technical perspective, which was more characteristic of the engineering principles and design methods. Interviewee C described the importance of the skills regarding engineering design he learnt at university:

[Interviewee C]: “They (the university staff) gave us some very good skills in terms of engineering design, so I actually understand how to design components, how to draw components, how to tolerate the thing, the specifications, assembly different manufacture processes, and all these things were really the core”.

About the feature of engineering principles and design methods, interviewee A and C shared similar understanding in that there were some fixed procedures and principles to follow in design:

[Interviewee A]: “Design sometimes can be just some procedures like following standards. It’s pretty straightforward.”

[Interviewee C]: “…It happened before, not the same project, but the same process, you know, the different brief, [but] the same idea we had done before. … It was different project each year, but the principle is the same and you start the same point during the year.”

The principles and procedures in design talked about by interviewee C were understood from a more holistic perspective by interviewee B, who regarded it as “thinking process” which went through stages from a list of objectives to the final required product:

[Interviewee B]: “The thinking process is the process from turning a list of objectives or a list of parameters into a viable, commercial proposal, so something that would work; you could price the work, so it would make profit, and you’ve looked up all components of the design, of the building, and you understand what has to be done in what order, how much product you need. You take all these into account. It’s that process that goes from lists of objectives to a full bid. That process, there is what the stages of the process it works, is what I learnt.”

However, different from interviewee A who saw design more from its fixed standards side, interviewee B understood design more from the thinking aspect, as he said:

[Interviewee B]: “It’s not standard procedures. It’s just the way of thinking. I think that’s what they are teaching in the university. I mean I’ve learnt specific standards, and specific ways of designing. I think the main thing you learn to do is engineering of course, or the design of course, is…how to think amongst the specific procedures, how you are going to design the columns, that kind of things.”

It can be seen that the basic things the interviewees learnt from doing design projects at university was related to the technical aspect of design, including the design skills/methods and engineering principles and standards. Besides this, the thinking ability along with the technical aspect in design was also regarded as an important aspect having been learnt out of design projects at university.
b. Engineering design as design thinking

The way of thinking by designers is often regarded as unique and different from the “epistemological inquiry process” in that the former is characteristic of divergent thinking while the latter is characteristic of convergent thinking (Dym, et al. 2005). In design situation, there exist multiple alternative known answers as well as multiple unknown possible answers, and design thinking is seen as a series of continuous transformation from the concept domain, in which divergent thinking operates, to the knowledge domain, in which the convergent thinking operates (Dym, et al. 2005)

Interviewee C talked about this nature of design from the design projects he did at university:

[Interviewee C]: “Certainly I think the freedom to think, or allowing the attempt of the divergent thinking is important. … I think what I learnt in the project is, the design project is the best when it’s set with no preconceived idea about what outcome is going to be.”

[Interviewee C]: “One of the techniques we were taught is not that it has the only one (way) that works, but one possible way of addressing the problem is to brainstorm.”

The divergent thinking practice can improve the creativity ability of students through design projects because design itself is to invent something new instead of following what others do, like interviewee C described:

[Interviewee C]: “There is another element in design, which isn’t design, which might be more drafting. Where I would say to somebody: this is my idea, this is what I come up with; this is how it’s going to work. Right, you would go and draw it, and that isn’t design. That’s just redraw it again.”

However, about the extent of divergent thinking in the initial stage of design, that is, the idea generation stage, interviewee C talked about what he found from his design project experience:

[Interviewee C]: “The initial stage of design is to come up with initial ideas. Then what actually happens is that the best idea is the first idea you as a group come up with.”

Interviewee C also explained the reason for the unnecessary of the convergent thinking application from the perspectives of time and budget constraints in the real design situation:

[Interviewee C]: “This rationale in the project [is] you should produce a number of initial ideas…. It sounds a sense of good learning, but in reality it doesn’t happen because there is no point of doing it. I mean we often have time constraints; we often have budget constraints, so ultimately getting it right at the first time.”

Accordingly, he talked about his suggestions for the learning of the early-stage convergent thinking ability at university:
Defining effectiveness in Engineering Design

[Interviewee C]: “…my belief is that in the initial stages you should quite contented to a small number of ideas, and then that idea should be developed further, and if as the development process continues, then that idea needs to divergent two or three or four separate ideas, but it shouldn’t be prescribed from the outset that there needs to be this massive range of initial ideas.”

What interviewee C talked about the convergent thinking in the early stage of design seemed to correspond to the different ways of design thinking between the expert designer and the novel designer discussed by Cross (2004). For most expert designers, they “become readily attached to single, early solution concepts and are reluctant to abandon them in the face of difficulty in developing these concepts into satisfactory solution” (Cross, 2004). Thus, “generating a very wide range of alternative may not be a good thing”, while “a relatively limited amount of generation of alternatives might be the most appropriate strategy” (Cross, 2004), as interviewee C suggested in the interview.

B Knowledge application

a. Reinforcement of old knowledge

One of the differences between project-based learning and problem-based learning is believed to be that the emphasis of project-based learning is generally on the application of knowledge, while the emphasis of problem-based learning is on the acquisition of knowledge” (Perrenet et al., 2000; Prince and Fedler, 2006).

Interviewee F talked about his understanding of knowledge application in the design projects at university.

[Interviewee F]: “I think not necessarily new (knowledge), but something helps to confirm what is taught for us…maybe something that I wasn’t quite confferable that before, but you then start to see how things are applied. So it's not brand new knowledge, it's more application and reinforcement of knowledge you've given previously”.

In the process of knowledge application and reinforcement in design projects, however, the previously learnt knowledge can possibly be understood to a broader and deeper level:

[Interviewee F]: “By doing the design project you do get opportunity to apply things, and by going through the application of knowledge into something real, something you understand, maybe going on a little bit further, just to understand in a little bit more detail, then you certainly do get more.”

[Interviewee B]: “The outline of the process was taught, so the stages of producing a bid were taught, but a lot was learnt by ourselves, by actually doing it, you really understand it.”

Thus, the “learning by doing” in terms of knowledge learning from the design projects should
be more referring to a broader and deeper level of previous knowledge understanding instead of brand new knowledge learning.

b. The relation between theory and practice
To apply knowledge in design projects, students may rely on lectures alongside with the design projects as the equipment to undertake projects, or to draw upon knowledge from previous lectures (Savin-Baden, 2003).

About the role of lectures in design projects, interviewee C emphasized the importance of both of the theory and practice from his perspective:

[Interviewee C]: “For me, having been taught theory and rules by sb who is very well experienced, who is very knowledgeable in my field, is fundamental to understand the basic principles, but then there’s always the important part, which is applying that. I’m really reinforced that knowledge, all makes challenging what you’ve been taught to prove what does happen. … So I wouldn’t say either is more important. I think both are important, and certainly one without the other wouldn’t help, wouldn’t work.”

About the appropriateness of the amount of design projects at university, some interviewees gave the number of design projects they did at university and their opinions on its appropriateness, as shown in Table 4.5:

<table>
<thead>
<tr>
<th>Interviewees</th>
<th>Number of group design projects at university</th>
<th>Appreciation of the amount of design projects at university</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewee A</td>
<td>At least one per year</td>
<td>Appropriate</td>
</tr>
<tr>
<td></td>
<td>Main one in final year (individual &amp; group)</td>
<td></td>
</tr>
<tr>
<td>Interviewee C</td>
<td>Main one in 2nd year and final year respectively</td>
<td>Appropriate</td>
</tr>
<tr>
<td>Interviewee D</td>
<td>1-2 per year</td>
<td>Appropriate</td>
</tr>
<tr>
<td>Interviewee E</td>
<td>2nd year (2 months); 4th year (individual &amp; group; 6 months)</td>
<td>Appropriate</td>
</tr>
<tr>
<td>Interviewee F</td>
<td>One in final year</td>
<td>Too few</td>
</tr>
</tbody>
</table>

It can be seen that two of the interviewees, interviewee C and E, had at least two main design projects at university, which they believed to be of appropriate amount; another two interviewees, interviewee A and D, had at least one group design project each year, which they also thought to be of appropriate amount. One exception is with interviewee F who only did one major design project in his final year, and he thought that it was too few.

From the limited responses of interviewees, it can be seen that generally at least two main group design projects should be taken by students at university which can be likely to combine the
theory and practice well for students to grasp engineering design and the knowledge application.

C Transferable skills

a. Communication with team members

One of the skills expected in group design projects at university is communication. It was found in the interviews that the communication skills developed through design projects at university includes both the oral skills, like the interaction with team mates at technical levels and the group presentations, and the writing skills, like producing a report as a team.

Interviewee C described the communication skills he developed from doing design projects:

[Interviewee C] “If somebody said: ‘what you learnt? What did you get out in this project?’ Maybe I can’t write down, but I think still there is somewhere at the back of mind…They picked up the skills, the interaction [skills] they learnt…for example, how to produce a report with other people, how to discuss technical ideas, all these soft skills.”

Interviewee A talked about the value of communication within the teamwork, which helped her learn how to become part of a team, like tolerating and accepting team mates’ work:

[Interviewee A] “One of the most valuable things we did in the last one [project] that I remember was how to communicate, because the work I was doing was dependent on the other seven people, and theirs were dependent on mine as well, so it was really important that there is communication between us…. so [from it] you learn how to become part of them….Because everything you want in your working comes from the group, you have to accept many, many things that other people have, and then keep on that”.

b. Sense of responsibility

Sense of responsibility is an important element which fosters the success of the teamwork in group design projects. In the interview, the responsibility for the teamwork was learnt from two perspectives: completing work in time and taking the fair amount of work.

Interviewee A talked about the sense of responsibility from the perspective of time management:

[Interviewee A]: “It’s part of a team, and there is a natural responsibility for others, then there’s responsibility for myself, I had to be reliable to others as well. If I had a deadline for specific information, I had to have that information not delayed”.

Interviewee B, on the other hand, more stressed the responsibility for the amount of work he should take for the team:

[Interviewee B]: “The fact that there are other people in the team with you as well means that, … you would like to let the team down if you didn’t do much yourself.”
c. Leadership

Leadership ability was another aspect some interviewees learnt from the group design projects at university. Interviewee E described the responsibility he held for being a leader in the group work:

[Interviewee E]: “In the final year I adopted the role of chairman of the group, responsible for organizing meetings, distributing group work, preparing meeting agendas, putting together the final report and ensuring the project remained on track by preparing regular project plans.”

It was found that the previous experience was one of the reasons for taking the leadership role within the team:

[Interviewee E]: “I decided to put forward my name for group chairman on the basis that the design project was based on a pharmaceutical processing plant, which I had experience of during my time at Avecia on my industrial placement. I felt that my experiences in this industry would allow me to provide some guidance to the group, especially during the early stages of the project when we were developing feasibility studies and design concepts.”

However, it was also found that not all the leadership role was successful in design projects at university. Interviewee B told his experience of being a leader of a group design project in which he had to take most amount of the work:

[Interviewee B]: “The group I was with was not working as efficiently as I wanted them to, so I found myself did a lot of the work, unfortunately…. I found problems getting them to do the work.”

He described his ways of settling the problem as a team leader:

[Interviewee B]: “I had to meet with them. I express my concerns, verbally and in emails. I also expressed my concerns to the lecturers, and told them it was not acceptable.”

There seemed to be two reasons for the difficulties in leading the team for Interviewee B. One was his team mates’ attention to other parallel courses. The other was the higher standard he wanted to seek than his team mates:

[Interviewee B]: “We had a lot of other courses at the same time, and the other group members were spending time doing other course work. …They had other priorities as well at the same time.”

[Interviewee B]: “Also, the kind of the person I am. I work quite hard. I like to do my best, so my standard was higher than their standard, I think…. They were happy with lower level of work.”

So for interviewee B, this experience of teamwork in which he was a leader was unhappy,
because the problems he encountered in his team were not settled to his satisfaction in the end:

[Interviewee B]: “The lecturers got involved. They told the people to work harder, but they still didn’t, and I did up most of the document myself. …I wasn’t happy with the settlement.”

Therefore, it can be seen that about the leadership, both positive and negative experience could be experienced, depending on how successful the teamwork was in the design project process.

d. Learning from individual differences in the team and team work skill development
The teamwork in group design projects at university provides opportunities for students to learn from their teammates. In the interview, it can be found that this learning generally resulted from the differences within the team members:

Interviewee A talked about her learning from the different ways her team mates adopted in the teamwork:

[Interviewee A]: “What else you learn from other people as well; some people may do it in another way, in a different way, so it can be really constructive.”

Interviewee C discriminated two kinds of skills as strengths in his team mates at university, analytical skills and practical skills, from which other team members can learn and apply when necessary:

[Interviewee C]: “I’m in a group design project which is, like I said, different people got different skills and strengths, especially when you get the later years of a degree programme; some people take the route of a very analytical person, some others go as a practical person, … And I think by working in a group you have other opportunities to learn from those people, so use those skills when you have to use because in reality you are not so respective enough, you would rely on specialists to help you out what you need to”.

The appreciation of and learning from the team mates’ differences can help develop the ability to work with people of differences, as interviewee pointed out what he developed from the teamwork at university:

[Interviewee D]: “[From the design projects] I developed the ability of working with a group of people with different agendas, experiences, strengths, weaknesses and needs.”

e. Self-directed learning
Project-based learning is characteristic of its student-centredness and self-directeness. In the interview, it cal also be found that the self-directed is twofold: individual-self-directed and team-based self-directed.
Interviewee C talked about the feature of individual self-directedness in the design projects:

[interview C]: “In order to get to the design process, we had tutors, we always had mentors, but they weren’t directly say this is what you got to do this, this is what you got to do next, so it was very open-ended, very student-led self-directed.”

Self-management, especially in time, and self-organization were particularly learnt as the improvement of self-directed learning ability from the design projects:

[interview A]: “Yes, organizing yourself, self management of your time, well, definitely these you have to learn at the university. Any way, no one is up to chase. You have to do your homework; you have to be responsible.”

[interview C]: “There were lots of learning opportunities, specifically learning from that time management, such as making sure that you complete the right stages, stages of the process by the right time, that sort of things.”

Team-based self-directed learning was described by interviewee A, who talked about the effort her team made for building communication systems in the design project:

[interviewee A]: “we had an [electronic] platform we were employing the information, while we all had our initiative. ... It wasn’t sth compulsory. We just undertook for it to work out. We had to have communication systems. That’s what it was.”

4.2.4.3 Effectiveness of University Design Projects for Engineering Graduates at Work

From the interview, it was found that all the three categories of learning discussed above, namely, engineering design, knowledge application and transferable skills, had effects on the engineering graduates’ present work. The former two categories, engineering design and knowledge application, had different effects between the engineering graduates’ work which was non or loosely relevant with engineering design and that which was closely related to engineering design; the last one category, transferable skills, had similar effects on all these engineering graduates. The details of the differences and similarities of the effects were shown in Table 4.6:
A. Effectiveness of engineering design and knowledge application

In the effectiveness of engineering design, interviewee B stressed the usefulness of the broad thinking ability for his present work rather than design because of the nature of his work, which did not involve engineering design:

[Interviewee B]: “Very useful [in] how to think in broad sense. When you are given a problem, and when to go from very, very broad sense, the large scale, going down to the very, very specific, in that sense, I think.”

[Interviewee B]: “That’s (the thinking process) more important than design [in my present work]. My present work does not include design. It is more management than design. You have designers do the design, and we need information from them, we use their information.”

Interviewee A expressed the similar opinion by stressing the importance of the way of thinking in present work:

[Interviewee A]: “I’m not doing design now, but I think one of most important things is how to think what you need, how to product the thing, and that’s really applicable to real life…”

Likewise, because of the loose relevance with design in the present work, interviewee C felt that what he learnt in design projects can not be applied directly to his present work. What he could apply was what he called “surrounding knowledge”:

[Interviewee C]: “I don’t think there is anything I learnt directly I can apply today. … I’m not a designer. …What I’m able to apply is more the superficial learning, more the surrounding knowledge:…the analysis process, the tool you can use, the ability to use to design CAD, do practices, and drawing practices, … all those sort of things really, yes, directly, directly applicable.”
Furthermore, interviewee C talked about the different usefulness of what they learnt from design projects between him and other people whose work involved design:

[Interviewee C]: “... I know somebody, for example, now works in structure design, and the university design projects, they are all structure design, then they would directly be able to use them; whereas what I’m able to learn, …, the knowledge not necessarily directly applicable. I’m not able to take everything I learnt from the project and apply directly to what I’m doing today”.

Such differences were also obvious between the interviewees in this research. For interviewee D and E whose work involved engineering design, they felt that the design projects at university “mirror” their present work and thus very helpful technically:

[Interviewee D] “It mirrors my present work well … Helpful [in the sense of] engineering principles, methods of undertaking design, ensuring you understand the client’s requirements, etc.”

[Interviewee E]: “I work for an engineering consultancy firm, which specialise in design projects for the food, beverage and pharmaceutical industry. All elements of a student design project are involved from preparing project plans, developing block flow diagrams and utilization charts to the more detailed design of equipment and services and finally full commissioning and testing (obviously not able to cover in the student design project).”

By contrast with interviewee B who benefited from the broad way of thinking in his work, interviewee E stressed the attention to details as an important attribute in design which he benefited from the university design projects:

[Interviewee E]: “A very important attribute in design work, the design project at university taught me to check my own and others work for detail. Whilst less important from an academic level, the real-life ramifications of missed details can be costly (not just from a financial level but from the perspective of product quality and health & safety).”

B. Effectiveness of transferable skills
In the aspect of the effectiveness of transferable skills in present work, most of the interviewees shared some similarities in terms of team work ability, communication ability, leadership, confidence and self-directed learning ability.

In the aspect of the effectiveness of team working ability, the teamwork experience in design projects at university can help graduates in their ability to interact with people at work, especially working with different team members:

[Interviewee D]: “I worked in a range of teams, so the experience of coping and dealing with different team members, as both a leader and part of the team, was useful.”

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[Interviewee A]: “I don’t know how the work is in other sectors, but in this sector if you have something to certain success, we have to know how to think and integrate with other people. …It has to be coherent, that’s definitely the things I learnt in the university - how to produce some of the early coherent intergrowth.”

The communication ability developed from the design projects at university was also effective in terms of communicating at technical levels, with people of different professional backgrounds at work as well as the presentation ability.

[Interviewee E]: “Developed the ability to converse on a technical level and communicate ideas with people from a variety of professional backgrounds.”

[Interviewee E]: “From performing presentations throughout the university course. I have the ability to confidently present material to clients and external personnel.”

Leadership role taken at university was also helpful for graduates to build up their confidence and responsibility at work.

[Interviewee E] “By acting as group chair for the duration of the project, this experience has encouraged me to seek a responsible and senior position within my career; … has allowed me to confidently drive forward parts of designs for which I am responsible. I can now make important decisions including the approval of technical drawings and the ordering of expensive plant equipment.

Not only because of the experience of the leadership role in the design projects at university, but also the experience of the design projects themselves can help build up graduates confidence in their work:

[Interviewee C]: “It’s always very helpful (that) you learnt the theory and then you always saw the practical application aspect…. [When] I gather back in mind, yes, I’ve done that, I’ve seen how that happens, I’ve seen how to do that, I know what should be expected, what should be looking for. …It makes you be more confident in what you are doing, whatever sort of project which you might be given.”

In the aspect of self-directed learning, most interviewee talked about the importance of self-directed learning at work. In most circumstances, self-directed learning was the typical way of learning for graduates at work:

[Interviewee A]: “Self-directed learning is paramount because once you graduate and work in industry. You are ultimately going to learn by yourself. You may have other people to talk to, but ultimately you are only there.”

[Interviewee B] “It’s very unusual it might be the case of someone coming and telling you, ‘This is what has to do’, other than you find out what it is, and what to do, so it’s my own interest.”

Unlike merely applying old knowledge in design projects at university, the self-directed learning
at work often involved learning new knowledge in practice. In this sense, the “learning by doing” at work was different from that in group design projects at university:

[Interviewee E]: “My job is heavily based around learning by experience. Being a small sized company with a limited number of process engineers available for regular support, it is quite often the case that I will have to teach myself about a particular subject matter.”

[Interviewee A]: “Usually the line manager asks to do sth, then you have to go away and plan how you can do this. And then by doing this, you will understand it all the way through. Recently I’ve done a sale marketing strategy for a company. I’ve not done it before, so I had to start from understanding the sale strategy: what is a marketing sale strategy, how do we break it down, and then how do we assess the different component and put strategies behind them. By doing this project I understand it…This is how I learn in the work.”

The skills of asking questions developed in design projects at university helped the self-directed learning in present work. This was mentioned by interviewee B:

[Interviewee B]: “The way I think in the university, for example, questioning sth, questioning the way that I’m going to do it, the same way [at work] as I used in the university….For me, personally, was research through internet, research through books, and also speaking to people in industry. I know experienced people from landlord before I came, so I used to pick up the phone and speak to them and ask them questions”.

4.2.4.4 Suggestions for the Engineering Design Courses by Interviewed Engineering Graduates

A. Nature of design education from the perspective of graduates

Engineering design is generally seen as distinguish from the hard science by its nature of application. Interviewee C talked about his understanding of engineering education – a combination of science with application:

[Interviewee C]: “I see engineering education as science with application, and practical which is in design and the manufacture and techniques, and on the other side there is the maths, the analytical stuff and theoretical stuff.”

And the learning of design was believed to be harder compared with the learning of the science knowledge because in design learning the understanding and appreciation were necessary:

The two are very different: science, the maths, the fluid-, and thermodynamics, all that kind of stuff, can be taught in our textbooks relatively easily because, you know, they are black and white. There are equations that you have to learn; you put numbers. And on the other side, the design, the manufacture processes. That was something which is, I think, harder to teach, and it’s something which you get as a person. As an engineer, you have to have the appreciation; you have to understand these things; it’s always kind of the second nature.

To have effective design learning, learning by doing was emphasized by interviewees:

Defining effectiveness in Engineering Design
Defining effectiveness in Engineering Design

[Interviewee C] “The way that sort of stuff, the design and chores, if it’s going to be effective, has to be different from these analytical stuff because you have to be doing, you have to be really applying it.”

[Interviewee B]: “The outline of the process was taught, … but a lot was learnt by ourselves. By actually doing it, you really understand it”.

Besides the learning by doing nature, the social nature of design was pointed out by interviewee D:

[Interviewee D]: “Design work is, or at least should be, a team exercise as it requires development of ideas from a range of sources and then cross-checking. Therefore working in teams during design projects at University mirrors the requirements to do so in real life.”

B. Differences in design projects at university and at work
From the interviewees it was found that differences existed between the design projects at university and at work. The differences fell into two categories: one was in the design project itself; the other was in the team mates. A summary of the differences was shown in Table 4.7:

<table>
<thead>
<tr>
<th>Design projects</th>
<th>Team mates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project objectives</td>
<td>Qualification of team members</td>
</tr>
<tr>
<td>Time constraints</td>
<td>Levels of involvement</td>
</tr>
<tr>
<td>Budget</td>
<td></td>
</tr>
<tr>
<td>Extent of details</td>
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</tr>
</tbody>
</table>

a. Design projects
Design projects at university are often criticized by being not realistic enough. The engineering graduates talked about the features of (design) projects in industry which they found different from those of the design projects they did at university, including project objectives, time constraints, budget and the extent of details.

1) Project objective
The objective in projects at university and at work was different in that in the former the objective was learning whereas in the latter the objective was project completion. Interviewee A talked about this from her perspective:

[Interviewee A]: “… In the university you might get more help with information about it from handouts. They are trying to stimulate the teaching of it. It’s not the real exercise. Their objective is that there you learn, whereas my line manager’s objective is if the job gets done”.

2) Time constraints
Interviewee C talked about the different time constraints between university design projects and the ones in industry, pointing out that the time constraints in industry was more collected with cost, and hence much tighter:

[Interviewee C]: “There are time constraints in industry. It’s much tighter. … In the real design if you get it done quickly you can save more cost, so I think the time constraint is a big one [difference].

Interviewee A talked about the different effects of time constraints on the way of handling projects. At university, the content of what to do was more flexible than that at work.

[Interviewee A]: “Definitely, (in the uni) we have to meet the deadline, but… because we were asked to decide to what we are going to design, if we think sth wasn’t feasible, we wouldn’t change the deadline, but would change the title or the actual materials in the design project, so I wasn’t really stick. If there was a case that they say that there was sth that was not feasible in time, then I wouldn’t do it, whereas now [at work] you have to do it.”

3) Budget
Budget was another difference talked about by interviewees. In industry, the flexible budget tended to ensure more successful final product than at university.

[Interviewee C]: “We don’t come with tight budget in industry…. [In industry] if you do things properly by being able to spend money, you would end up with sth, for example, spend money on tools and that sort of things, and that ultimately leaves too much more successful product. Those opportunities aren’t available within the university.”

4) Extent of details
Interviewee C talked about the difference of details in industry projects and university projects from the perspective of wholeness. In industry, some of the work in the project process was not necessarily to be done as in the university:

[Interviewee C]: “Another difference is that the university design project is very ideal. It starts with initial ideas and developing the ideas, pre-product specification, and you do some, a lot of research. … and all of these stuff, which is all absolute stuff, it takes an academic year to get from the start to the end of design. Now in reality - I would not say those are not useful, - but in reality you don’t [have to] get it done…Take the FMEA for example, we don’t do it to that level of detail because sb has probably done that before which would be very similar - we just consult it.”

By comparison, interviewee E emphasized the importance of paying attention to the details for the sake of cost, quality and safety, which he found devalued in university design projects:

[Interviewee E]: “Whilst less important from an academic level, the real-life ramifications of missed details can be costly (not just from a financial level but from the perspective of product quality and health & safety).”
b. Team mates

In terms of team mates, it was found that issues existed in both university design projects and projects at work, but of different features.

Interviewee B who had an unhappy group design project experience at university talked about the differences from the perspective of qualification and contribution of the team mates. He felt that the quality level of students at university was unbalanced, which might cause the difficulty in fitting them together, as what he experienced at university; while there was not such problem at work, because the people recruited at work generally had similar qualification and willingness of contribution.

[Interviewee B]: “At university, there was a pool of people, some of them good, some of them bad, and they all have to fit. In employment, people have to be recruited because they have a skill, so they have been taken on and paid because they can contribute this area of work, so even if you do not select them, you get people who want to be there, and qualified to be there, whereas in the university you don’t always get that”.

Different from interviewee B, interviewee E talked about the issue of team mates from the perspective of the academic background. For him, working with team mates at university was easier because the students shared similar technical background, while at work the different professional backgrounds of the people in teams caused difficulty in coordination and cooperation.

[Interviewee E]: “For chemical engineering student design work, everyone has the same technical background so there is a good level of process understanding throughout the group. However in reality there are team members from many different professions (process, mechanical, civil, electrical, software) so it is occasionally difficult to get all groups co-ordinated and working together within a particular project.”

Interviewee A shared similar view with interviewee E in that the people working in a team at work coming from different sectors and involved in multiple parallel projects, which caused the different dedications of team members.

[interviewee A]: “It’s not so organized as in the university, it’s all coming from different sectors, I would say….There are also some people involved in multiple projects who may not be able to dedicate as much time to a single project as others, so the level of involvement differs from person to person.”

C. Suggestions for the engineering design project course at university

Based on the differences of design projects at university and at work experienced by the engineering graduates, they put forward some suggestions for the improvement of the engineering design project courses. A summary their suggestions were shown in Table 4.8:
Table 4.8. Suggestions for the engineering design project courses.

<table>
<thead>
<tr>
<th>Suggestions</th>
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<tbody>
<tr>
<td>More realistic projects</td>
</tr>
<tr>
<td>More emphasis on business aspects, esp. budget &amp; cost</td>
</tr>
<tr>
<td>More emphasis on design process</td>
</tr>
<tr>
<td>More emphasis on details in design &amp; project planning</td>
</tr>
</tbody>
</table>

It can be seen that graduates’ suggestions mostly focused on the features of design projects. Interviewee C stressed the realistic aspect of the design projects at university and suggested to add more realistic constraints.

[Interviewee C] “I think it needs to be more realistic. … First of all, the project should be real projects, especially be real-life projects. Often [at university] they are set by academic tutors, and therefore, they are not real, they are just made-up; sometimes they are set by companies, but they are not real projects, the companies just make them up, the same make-up project…. Possibly we can do more realistic constraints such as time”

An appreciation and understanding of the business aspect of (design) projects in terms of budget and cost was repeatedly emphasized by graduates, and the good preparation for this in the university design projects was suggested as necessary.

[Interviewee B]: “So for me, more important on the commercial side of it, because it is all business driven commercially. …This is the focus, so someone doing design at university and they understand the calculations, but when they come to the work place, maybe they do not have a good enough appreciation of cost, of the commercial side of the management of people…”

[Interviewee C]: “Make sure there is a budget, a decent budget available, so if money needs to spend on the project [at work], then they [engineering graduates] would have the ability to do that.”

[Interviewee D] “Increase focus on designing for safety and the role of CDM, and on how to balance the cost of the design with buildability and programming.”

Conflicting suggestions in terms of whole process versus details can be found in the interviewees. Interviewee B, whose present work was not closely related with engineering design, suggested more focus on the process in design projects:

[Interviewee B]: “I think what you are looking at there for design, engineering design projects, there should be less focus on calculations, more focus on process, because in industry, in the real working world, it’s a process-led exercise.”

By comparison, interviewee E who worked in a design project company suggested more attention to details in design and project planning:

[Interviewee E]: “More emphasis on attention to detail in design work and more emphasis on project planning.
In retrospect our final report submission was lacking in a few areas (plant utilities and automation) with a major emphasis on concept screening. In reality the concept stage is only a small portion (10% at the beginning of a project) whilst the detailed design of a process including utilities, sizing of small equipment like valves and creation of control & automation documents is much more prevalent.”

4.2.5 Discussions

It can be found that the engineering graduates’ views on the effectiveness of university group design projects they experienced in their present work corresponded to a great extent to those opinions held by the design project module lecturers at university interviewed in this research. Similar three categories of learning effectiveness were identified, namely, engineering design, knowledge application and transferable skills.

4.2.5.1 Engineering design and knowledge application

It was within expectation that for the design related work, engineering principles and design methods can be more directly applicable than in the work that is loosely related with design. However, as the core of engineering activities, a proper understanding and appreciation of design was necessary for most engineering related work. The design process experienced in group design projects mirrors the industrial reality which helps graduates understand the engineering industry better. The way of design thinking from the broad to the specific also helps graduates to deal with problems in their work.

A difference was found between lecturers and graduates when they talked about design learning. It seemed that lecturers at university attached great importance to the creative and innovative aspect of design, which they think should and could only be learnt through practice of design. By comparison, engineering graduates seemed to attach more importance to the business aspect of design, emphasizing more the cost and budget. One reason for this is that the purpose of the graduates’ work is to produce economic value, so the issues related with finance are put to the front stage; the other reason lies in the relation between time constraint and budget in industry. One the one hand, the time constraint is much tighter in industry; on the other hand, the budget in industry is generally not so tight, leaving room for a trade off between the two:

[Interviewee C]: “We don’t come with tight budget in industry, but we do have a budget, so if it takes me a small amount of time, then I would spend a lot money and get some prototype, maybe initially, some samples made whatever. I might spend several thousand pounds, getting some stuff done, don’t get them done quickly but get them done well, spend money on tools and that sort of things, and that ultimately leaves too much more successful product, because if you do things properly by being able to spend money you would end up with something. That [kind of] opportunities aren’t available within the university.”

4.2.5.2 Transferable skills

In the aspect of the effectiveness of transferable skills, as generally claimed, they are very useful
in the real work context, whether design or non design related. However, in terms of team work skills and leadership, their usefulness was obvious for those graduates who experienced successful teamwork in group design projects at university. For the graduates who had unsuccessful teamwork, such as interviewee B in this research, no teamwork skills or leadership skills were mentioned to have been developed. For interviewee B, although the final mark of the group design project he did was good, grading A, he did most of the work and the group design project was no more than an individual design project, and he did not have the chance to learn from his team mates.

The reasons for the unsuccessful teamwork can be various. Research to date has identified the cognitive, psychological and cultural factors (Pauli, 2008). Interviewee B who had such experience thought that poor time management and low standard of learning goal by his team mates caused the down fall of their performance. These reasons are related to the self-directed learning ability and individuals’ personality (or motivation).

Self-directed learning ability could be developed in PBL. However, it should be noted that in the small group learning like PBL, self-directed learning is both the means and the end. That is to say, on the one hand, PBL is characteristic of self-directed learning and its success depends on it; on the other hand, self-directed learning ability is one of the learning outcomes in PBL. This caused a paradox in the development of self-directed learning in PBL – too much or too little supervision from the teachers may affect the development of it.

Motivation is a relatively old topic in the teaching and learning field. Compared with traditional lecture-based learning, PBL is more likely to motivate students to learn because of its student-centred nature. However, different levels of motivation may lead to unsuccessful team work. The reasons for the differences in motivation can be various: different learning standards, as in interviewee B’s design project, different learning styles in team work, different understanding of responsibility, different sense of satisfaction from the team work, different future career goals, etc. Among these, interest seemed to be the helpless one in teachers’ eyes, as lecturer C commented on his students:

“If students lack knowledge, teachers can help, but if they lack interest, then teachers can do little to help them.”

Unsuccessful teamwork in small group learning like PBL is an issue yet to be settled. Two basic measures have been used to settle this problem so far: one is the way of team formation, the other is assessment.

It can be found from the literature that there are various ways of team formation in design projects at university. Teams can be formed based on academic levels, or experiences of
In this research, interviewee E described the different ways of team formation in the design projects at university. The second year project he did was split into three subsequent phases and for each phase the groups were rearranged, thus throughout the whole project he worked with different people in each phase. In the final year project, the groups were split on an academic basis, with the higher achievers mixing with the lower achievers and the groups were kept the same for the duration of the project. Interviewee E reflected on the benefits and defects of the two ways of team formation:

“In retrospect the benefit of this method [in the second year project] is to introduce you to a lot of different people in a working environment, each with their own strengths and weaknesses. This is much like in the real world where you end up working with a wide variety of different people with different skills. The drawback of this method is that the quality of work in each phase felt highly inconsistent depending on who was in each group, groups were chosen at random with no balancing based on ability. …The benefit of this method [in the final year project] was that the group was able to build close working relations, and the students were able to develop roles within the group, each with their own sections of the project that they were in charge of. The groups were able to plan long-term goals. Again the group-based nature of the project was very like a real design project, with people adopting various roles and responsibilities during the course of the project.”

Interviewee E did not talk about the drawback of the team formation in the final year which was on an academic basis. However, it could be seen that the groups lasted throughout the whole project. Once the team work was not successful, it was not possible for the students to have the chance to change their team mates, like what interviewee B experienced.

The other measure to prevent potential crisis in team work is assessment. Generally peer assessment is used in group design projects at university, either paper-based or web-based. However, it should be known that assessment in group design project is very difficult, and is a controversial issue itself remained to be settled satisfactorily. On the one hand, the assessment is aimed to assess each individual’s contribution to the team work; on the other hand, the aim of the group design project is to build up teamwork skills by learning to “do it together without separate share of work” (from interviewed lecturer B). Therefore, it is a paradox between the assessment and the development of teamwork skills.

Therefore, it can be seen that more research should be done to prevent the unsuccessful teamwork and improve the quality of group design project learning at university.

4.2.6 Conclusions

Interviews were conducted with the engineering graduates to study the effectiveness of group design projects at university for their present work. Three categories of effectiveness were
identified, which were similar with the opinions of the interviewed lecturers, namely, engineering design, knowledge application and transferable skills. Differences in the effects on the work between different groups of graduates are mainly shown in the application aspects. Unsuccessful teamwork experience found in graduates indicates the necessity for more effective implementation in PBL.

4.3 CONCLUSIONS
This chapter is mainly focused on what the effectiveness of PBL is. Studies were made to identify PBL effectiveness categories from the perspectives of PBL teachers and engineering graduates via interviews. Similar categories have been identified between them. Varieties of the implementations were found from the lecturers’ interviews, which have confirmed what the literature review revealed. Unsuccessful teamwork found in graduates indicates that only knowing what the effectiveness of PBL is not enough, because how to achieve its effectiveness is still in the dark. This leads to the further study on the how issue of PBL effectiveness.
Chapter 5.

BUILDING THE MODEL OF GENERAL TEACHING AND LEARNING & DETERMINING KEY PARAMETERS OF PBL IN ENGINEERING DESIGN

In chapter 4, the content of PBL effectiveness in engineering design was studied from the perspectives of engineering lectures and graduates respectively. However, that study only explained what the effectiveness of PBL is; how to achieve the optimal effectiveness is still unknown, which is not enough for PBL implementation. From this chapter, the ‘how’ issue of PBL effectiveness will be studied.

5.1 BUILDING THE MODEL OF GENERAL TEACHING AND LEARNING AND ITS RELATION WITH PARAMETERS

5.1.1 Building of the Model of General Teaching and Learning

In PBL, as well as in general teaching and learning process, there are undoubtedly numerous factors involved. These factors can be internal (e.g. learner’s individual differences), or external (e.g. teaching quality and facilities); can be controllable (e.g. study skills), or uncontrollable (e.g. gender); can be quantifiable (e.g. intelligence), or unquantifiable (e.g. learning styles), etc.

All of these factors can be used to represent a certain teaching and learning approach, whether traditional or PBL. That is, all the factors can be taken as parameters of general teaching and learning, which can be represented as parameter 1, parameter 2, parameter 3, ..., parameter N, where N can be very many, even indefinite. Then we can get a schematic model of general teaching and learning using any of these parameters, as shown in the following Figure 5.1:

![Figure 5.1. A schematic model of general teaching and learning with certain parameters.](image-url)
5.1.2 Visualization of Insensitive Parameters in General Teaching and Learning Model

In the model of general teaching and learning, suppose we have two teaching and learning approaches, say, traditional approach and PBL. If the parameters selected in the model are not sensitive enough, that is, not distinctive enough, then the two teaching and learning approaches, traditional approach and PBL, will overlap with each other and not be able to be distinguished, as shown in the following Figure 5.2:

![Figure 5.2. Overlapping of two teaching and learning approaches with certain insensitive parameters.](image)

Therefore, in the model of general teaching and learning, only those parameters sensitive enough are to be considered and selected in order to distinguish two certain teaching and learning approaches.

5.1.3 Visualization of Sensitive Parameters in General Teaching and Learning Model

Suppose we have one such sensitive parameter, then a model of general teaching and learning with one sensitive parameter can be shown as in Figure 5.3:

![Figure 5.3. A schematic model of general teaching and learning with one sensitive parameter.](image)

It can be seen in Figure 5.3, in a model of general teaching and learning with one sensitive parameter, suppose there are two teaching approaches, for example, the traditional approach and PBL. When the values of the parameter in the two approaches, value X1 and value X2, are
different, i.e. value $X_1 \neq value X_2$, then the two approaches, that is, traditional approach and PBL, will fall into different ranges. In this way, it is possible to distinguish these two approaches. On the contrary, if the values of the parameter in these two approaches, i.e. value $X_1$ and value $X_2$, are the same, then the two approaches will fall into the same range, and accordingly they would be regarded as the same approach.

Suppose there are two sensitive parameters, then a model of general teaching and learning can be shown as in Figure 5.4:

![Figure 5.4. A schematic model of general teaching and learning with two sensitive parameters.](image)

It can be seen in Figure 5.4, in a model of general teaching and learning with two sensitive parameters, i.e. parameter 1 and parameter 2, again suppose there are two teaching approaches, for example, the traditional approach and PBL. When the values of the two parameters are different, i.e. value $X_1 \neq value X_2$, and at the same time, value $Y_1 \neq value Y_2$, then it can be said that the two approaches can be regarded as different.

Suppose we have three sensitive parameters, then a model of general teaching and learning can be shown as in Figure 5.5:
It can be seen in Figure 5.5, in a model of general teaching and learning with three sensitive parameters, i.e. parameter 1, parameter 2 and parameter 3, again suppose there are two teaching approaches, for example, the traditional approach and PBL. When the values of the three parameters are different, that is, value $X_1 \neq value\ X_2$, and at the same time, value $Y_1 \neq value\ Y_2$, value $Z_1 \neq value\ Z_2$, then it can be said that the two approaches can be regarded as different.

In this way, with the sensitive parameters being selected in the model of general teaching and learning, certain two teaching and learning approaches can be differentiated to an increasingly precise level.

The core of the research in this chapter is to find out and determine suitable parameters which are sensitive not only between PBL and traditional approaches but also between PBL approaches themselves. Only with suitable parameters, it can be possible to distinguish different PBL, as well as PBL and traditional teaching and learning approaches.

5.1.4 Factors Related with PBL Effectiveness from the Perspectives of Learning Theories and Curriculum Design

Learning is widely recognized as being a complex process. In PBL, as well as the teaching and learning in general, there are definitively numerous factors involved. In the following section, these factors were examined from the perspectives of learning theories and curriculum design.

5.1.2.1 Internal Factors

Here the internal factors refer to those factors characterised of and/or controlled by the learner. With the development of research on and understanding of the nature of learning, the role of the learner is increasing taken as important and influential in affecting learning effectiveness.
Cognitive psychology regards learning as resulting from inferences, expectations and making connections (Anderson, 2000; Schunk, 2004). In this perspective, learner’s plans and strategies as well as prior knowledge are emphasised, and learner’s individual differences, including differences in intellectual ability and personality along with differences in cognitive styles or methods of approach, are regarded as central in affecting learning (Hartley, 1998).

From the perspective of social and phenomenological psychology, learning is taken as a natural process. In this perspective, meaning is a personal thing and knowledge is socially constructed. Hence, learner’s feelings, emotion and experience are focused on (Hartley, 1998). Thus the internal factors affecting learning include learner’s own purposes and goals of learning, learner’s sense of choice, relevance and responsibility, self-regulation or meta-cognition skills (i.e. monitoring one’s own learning), learner’s conceptions of learning change, anxiety and emotion of the learner, etc.

5.1.2.2. External Factors
Here the external factors related with learning effectiveness refer to those factors outside and/or beyond the control of the learner. These include the factors related with the teacher and teaching quality, and the learning environment built around the learner.

1) Factors related with the teacher/teaching quality
In discussing the quality assurance in university teaching, Brown (1993) listed some teaching skills affecting the teaching effectiveness, including lecturing skills, small group teaching skills, laboratory teaching skills, research and project supervision skills, etc.

In recent decades, teacher’s beliefs/concepts have been regarded as one of the important factors related with teaching effectiveness. Teacher’s different ways of looking at the nature of learning and teaching lead to their different approaches to their teaching and different ways of treatment to the learner. In a model for understanding teaching and learning in higher education, Prosser and Trigwell (1999) include such factors - teacher’s prior experience, teacher’s approaches to teaching, teacher’s perception of his/her situation and teacher’s situation - as important.

2) Factors related with the learning environment
From a cognitive perspective, teaching is regarded as “the creation of learning environment in which students maximize the possibility of executing the cognitive activities necessary for building knowledge and reasoning capacity” (Floden, 2001). Generally, the cognitive psychology emphasized well-organized and clearly structured instruction, perpetual features of tasks and cognitive feedback (Hartley, 1998).
The social and phenomenological psychology, on the other hand, emphasizes the realistic setting of learning, and regards social situations (e.g. group atmosphere, etc.) and discussion about learning as important factors affecting the success and satisfaction of learning (Hartley, 1998).

Among all these parameters analyzed above, some of them would be more sensitive and distinctive than the others in studying PBL and the difference between PBL and traditional teaching and learning. It should be noted that this is not to say that some parameters are more important than the others, but that these parameters are more sensitive in distinguishing PBL and traditional teaching and learning. In the following section, the most relevant and sensitive parameter(s) of PBL were to be determined.

5.2 DETERMINING PARAMETERS OF PROJECT-BASED LEARNING

Based on self-directed learning theory and learner engagement theory and with the key role which both self-directed learning and learner engagement played in PBL, the two learning factors - self-directed learning and learner engagement - were identified and determined as sensitive parameters of PBL.

5.2.1 Parameter 1 of PBL – Self-directed Learning

5.2.1.1 What is Self-directed Learning?

The concept of self-directed learning can be traced back to the time of ancient philosophers like Socrates, Plato and Aristotle. In the relation between teaching and learning, Socrates emphasized the priority position of students’ thinking and learning by themselves. He held that the main role of the teacher is to guide and facilitate students’ learning instead of controlling their learning role. His idea passed down to Plato and Aristotle, with the former emphasizing student self-reflection, and the latter student self-monitoring and self-regulating in learning (Pang, 2004).

The idea of self-directed learning was later noticeably advocated by Dewey and Rogers (Brown, 2004; Pang, 2004). Dewey (1925) emphasized the freedom and democracy in teaching and learning which can provide students with opportunities to explore knowledge by themselves. Rogers argued from the humanistic perspective that the objective of teaching and learning involves developing fully functioning persons, thus students should be set free for self-directed and self-reliant learning (Brown, 2004).

In the 1970s, Knowles’s work Self-Directed Learning, A Guide for Learners and Teachers (1975) represented the re-reorganization trend of this learning approach. Knowles used the term self-directed learning as the opposite to that of teacher directed learning, and self-directed
learning is defined in its broadest meaning as “a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes.” (Knowles, 1975, p18)

Candy (1991) further described self-directed learning as having at least four meanings: personal autonomy, the ability to manage one’s own learning, independent learning outside of formal institutions and lifelong learning.

Boud and Higgs (1993) defined self-directed learning as an approach to learning in which the behaviour of the learner is characterised by 1) responsibility for and critical awareness of, his or her own learning process and outcome; 2) a high level of self-direction in performing learning activities and solving problems which are associated with the learning task; 3) active input to decision-making regarding the learning task; 4) the use of teachers as a resource persons.

The different understandings of self-directed learning so far can reflect three groups of educational ideas summarized by Boud (1988). Put it simply, they are

1) a goal of education;
2) an approach to educational practice;
3) an integrated part of learning of any kind.

Knowles’ definition of self-directed learning mainly emphasizes the process of self-directed learning, regarding self-directed learning as an instructional/learning method (Guglielmino et al., 2004); Candy’s definition more emphasized the learning goals (Brown, 2004); Boud and Higgs’ definition more emphasized the learners’ behaviour characteristics, as an integrated part of learning of any kind, such as project-based learning (Boud and Higgs, 1993)

5.2.1.2 The Role of Self-directed Learning in PBL

About the role of SDL in PBL, two points can be made:

1) Compared with that in the traditional teaching approach, which is usually lecture-based, or mostly lecture-based, the amount of SDL in PBL is generally significantly greater. Although in traditional lecture-based teaching approach students may also have a certain amount of SDL, for example, making study plans, searching references and reading materials, self-evaluation, etc., the amount of SDL is limited and the majority of learning is completed with the guidance of the teacher, such as lecturing, assigning assignment, supervising. Hence, the amount of SDL is significantly different between PBL and traditional, lecture-based learning.
2) Within the PBL approach itself, there are different ways of implementation which range from the pure self-directed project plus tuition to different hybrid forms which involve different amount of lectures, projects, and tuition. Further, on close examination, a hierarchy of student SDL can be found in the different ways of PBL implementation:

First layer, the average amount of all students' SDL vs the amount of teacher control, for example, different amounts of lecture, different degrees of freedom in choosing projects, different amounts of tuition, etc.

Second layer, the amount of individual student's SDL vs other individuals' SDL within teamwork, for example, different responsibilities and shares of work within the team, different roles of team members, different extent of leadership, etc.

From the above analysis, it can be seen that SDL can not only be used to distinguish the difference between traditional, lecture-based learning and PBL, but also that between the different ways of PBL implementation. Hence, based on self-directed learning theory, it is proposed that the amount of students’ SDL be a characterization parameter of PBL.

5.2.1.3 Quantification of Self-directed Learning Time as Parameter of PBL

In PBL, students’ amount of SDL work can be observable and measurable. One way of it is to be quantified by learning time.

5.2.1.3.1 The role of time in learning

Time as a variable in the teaching and learning process, especially time spent on learning, has been continuously regarded as an important determinant of degree of learning, and a crucial factor in influencing achievement (Carrol, 1963; Gettinger, 1985; Gijselaers and Schmidt, 1995; Kolari et al., 2008).

In the theory of Carrol’s model (1963), the degree of learning is proposed to be a function of time actually spent on learning and time needed to learn (Schunk 2004). Accordingly, the optimal degree of learning can be achieved when time actually spent on learning equals time needed to learn. Carrol’s model was conceptualized as an individual differences framework in which the degree of individual student learning was explained through two individual time variables: time spent and time needed (Gijselaers and Schmidt, 1995). Although not specifically applicable to higher education, the influence of his model is paramount. However, the model itself is abstract in two aspects which makes it hard for practitioners to implement: 1) time spent on learning can be multifaceted (see the family of concepts in Berliner, 1990); 2) how and who
should determine time needed to learn? It is also vague in that there might be different times needed to learn for different degrees of learning.

In order to make the model more adaptable to the classroom setting, subsequent research on time refined Carrol’s model and moved the focus from individual learning time to the instruction time (the time when the instructor and learners are in direct contact), and generally positive correlations between instruction time and learning achievement were reported (Gettinger, 1985; Gijsselaers and Schmidt, 1995; Van den Hurk et al., 1998). Further, the relation between instruction time and time spent on students’ self-study was also studied, especially in higher education. Findings showed that instruction time is a crucial factor in enhancing learning, but exceeding an optimal amount of instruction time may lead to the decrease in the time spent on self-study (Gijsselaers and Schmidt, 1995).

5.2.1.3.2 Past studies of the role of SDL time on PBL
The findings of the above research were mostly conducted in the traditional, lecture-based settings in which the teacher’s instruction and control played a major role in students’ total time for learning. By contrast, in the PBL setting, as well as the settings of other constructivist approaches, students are required to take more responsibility for their own learning, and accordingly, time for students’ self-directed learning, either individually or in teams/groups, can be expected to take up a greater proportion of students’ total learning time than in traditional settings. Then, how is the role of the time variable different in PBL rather than traditional settings?

Two related research reports can be found on problem-based curriculum in higher education. Gijsselaers and Schmidt (1995) studied the effects of quantity of instruction on time spent on self-study and achievement. They found that quantity of instruction in itself does not facilitate achievement; instead, students benefit more from time spent on self-study than from participating in traditional instructional activities. Also, similar to the findings of Vos (Gijsselaers and Schmidt, 1995), they found that time spent on self-study is a function of the degree of time allocated to instruction, and the two time variables may constitute a trade-off mechanism. Accordingly, they suggested an optimal balance between instruction and self study should be achieved to improve the effectiveness of instruction activities, but how to achieve this optimal balance was not touched.

In the second report on a problem-based curriculum, Van den Hurk et al. (1998) investigated the relationship between time spent on individual study and academic achievement which includes short-term knowledge, in the form of a block test taken every six weeks after a certain amount of content is covered, and long-term knowledge, in the form of a progress test taken four times a
year. Results showed a poor correlation between time spent on individual study and scores in both short-term knowledge and long-term knowledge.

5.2.1.3.3 Quantification procedures of SDL in PBL in this research

A. Operational definition of SDL in PBL

Based on self-directed learning theory and the role of SDL in PBL, SDL includes two general dimensions:

1) individual takes the initiative in learning both individually and in the team/group work; and
2) individual takes the initiative in learning in both formal and informal settings.

Derived from these two main dimensions, there are four main types of self-directed learning in PBL. They are

1) individual takes the initiative in learning individually in formal settings, such as individual’s ask questions and discuss with teacher in class;
2) individual takes the initiative in learning individually in informal settings, such as individual private study after class, or individual discussion with teacher after class;
3) individual takes the initiative in learning in team/group work in formal settings, such as the team meetings in and outside of class;
4) individual takes the initiative in team/group learning in informal settings, such as individual’s involvement in team/group discussion by email, or informal chatting with peers after class, etc.

The four types of self-directed learning were taken as the operational definition of self-directed learning in this research. The four types of SDL in PBL can be shown in the following formula:

\[ \text{SDL} = \text{individual’s private study} + \text{individual’s involvement in teamwork in formal and informal settings respectively} \]

B. Quantifying SDL in PBL

Based on the four types of SDL identified above in the formula, if we use time to quantify SDL, then the formula would become

\[ T_{\text{SDL}} = T_{\text{individual’s self-directed private study}} + T_{\text{individual’s self-directed team/group work}} \]

in formal and informal settings respectively, where T stands for time.
It should be noted that each PBL implementation may be unique, for example, the length of the projects, the length of the PBL courses, etc. Such difference should be taken into consideration in order to make it possible for different PBL implementations to be compared with each other. Therefore, the average amount of SDL can be represented as the percentage of the total time spent by each student instead of by absolute total numbers of hours. Hence, the SDL time in this study can be further represented as

\[
T_{SDL\%} = \frac{T_{individual's \ self-directed \ private \ study} + T_{individual's \ self-directed \ team/group \ work}}{T_{individual's \ total \ time \ spent \ on \ module \ (both \ self-directed \ and \ teacher \ directed)}}
\]

in formal and informal settings respectively, where T stands for time.

Now with the average amount of SDL time as the percentage of total time, the different ways of PBL implementation can be compared at the same level.

5.2.1.3.4 The Schematic model of PBL effectiveness with SDL as parameter

Now with the quantified SDL, it is possible to study the relation between SDL and PBL effectiveness. Their relation could be shown in the following schematic model:

In this model, the horizontal axis, T_{SDL1\%}, T_{SDL2\%}, T_{SDL3\%}, ..., T_{SDLn\%}, represents the percentage of SDL time which, as parameter of PBL, also represents the types of PBL. The vertical axis represents PBL effectiveness. Then, by examining the relation between the percentage of SDL time and effectiveness values, the optimal proportion of SDL time, that is, the optimal type of PBL can be determined and the trend of PBL effectiveness can be identified.

5.2.2 Parameter 2 of PBL – Learner Engagement

5.2.2.1 What is Learner Engagement?
Learner engagement is also called student engagement or student involvement (Astin, 1984; Kuh, 2001). Although seemingly self-evident in its meaning, this term was considered to be a *buzzword* in education circles, and there is little consensus as to how to define it.

Generally speaking, definitions of learner engagement usually include a psychological and behavioural component, as can be seen in the two trends of definitions in the research area of learner engagement:

In the first, student engagement has been used to depict “students’ willingness to participate in routine school activities, such as attending classes, submitting required work, and following teachers’ directions in class” (Chapman, 2003). Defined in this way, school engagement overlaps considerably with compliance, which in its more general form involves meeting expectations implicit in school contexts (Chapman, 2003).

The second definition used focuses on more subtle cognitive, behavioural, and affective indicators of student engagement in specific learning tasks (Pintrich and Schrauben, 1992). The details of the definition include (Chapman, 2003):

i. Cognitive criteria, which index the extent to which students are attending to and expending mental effort in the learning tasks encountered (e.g. efforts to integrate new material with previous knowledge and to monitor and guide task comprehension through the use of cognitive and meta-cognitive strategies),

ii. Behavioural criteria, which index the extent to which students are making active responses to the learning tasks presented (e.g. active student responding to an instructional antecedent, such as asking relevant questions, solving task-related problems, and participating in relevant discussions with teachers/peers), and

iii. Affective criteria, which index the level of students’ investment in, and their emotional reactions to, the learning tasks (e.g. high levels of interest or positive attitudes towards in the learning tasks).

5.2.2.2 The Role of Learner Engagement in PBL

In recent decades, learner engagement is increasingly seen as an indicator of successful classroom instruction as well as a valued outcome of school reform. The importance of student engagement in the teaching and learning process has been repeatedly recognized.

The NSSE project identified five indicators of learner engagement based on large-scale survey among college students. They are: level of academic challenge, active and collaborative learning, student-faculty interaction, enriching educational experience and supporting campus environment (Kuh, 2003).
Astin’s study of college student engagement in the US also found that two factors—interaction among students and interaction between faculty and students—were most predictive of positive change in college students’ academic development, personal development and satisfaction (Smith et al., 2005). Similarly, relevant research showed that the degree to which the student is actively engaged or involved in the undergraduate experience is one of the crucial factors in the education development of undergraduates.

Project-based learning (or team projects), along with other constructive learning approaches, is regarded as effective instructional interventions which can better engaging undergraduate students, compared with the traditional lecture-based teaching approach because of the supporting interactive learning environment it provides to the student.

“Teaching is to engage student in learning” (Smith et al., 2005). As an indicator of successful instruction, the more students engage in PBL, the better the PBL will be. Thus, learner engagement plays an important role in PBL and is suitable for being a parameter of PBL.

5.2.2.3 Quantification of Learner Engagement as Parameter

There are several methods to measure student engagement, including self-reporting such as survey, questionnaire, checklists and rating scales. Researchers also use direct observations, work sample analysis and focused case study (Chapman, 2003).

Self-report measures have been used by many researchers to assess the behavioural, cognitive, and affective aspects of task engagement. Items relating to the cognitive aspects of engagement often ask students to report on factors such as their attention versus distraction during class, the mental effort they expend on these tasks (e.g. to integrate new concepts with previous knowledge), and task persistence (e.g. reactions to perceived failures to comprehend the course material). Students can also be asked to report on their response levels during class time (e.g. making verbal responses within group discussions, looking for distractions and engaging in non-academic social interaction) as an index of behavioural task engagement. Affective engagement questions typically ask students to rate their interest in and emotional reactions to learning tasks on indices such as choice of activities (e.g. selection of more versus less challenging tasks), the desire to know more about particular topics, and feelings of stimulation or excitement in beginning new projects (Chapman, 2003).

The NSEE project used method of self-reported survey to assess college students’ engagement across the US. The benefits of using self-report measures are that they can not only quantify the items regarding learner engagement by asking the question of whether students are engaged in
learning tasks (e.g. Likert type scale), but also provide indication of why this is the case (Chapman, 2003).

5.2.2.4 The Schematic Model of PBL Effectiveness with Learner Engagement as Parameter

With learner engagement being quantified, it is possible to study the relation between LE and PBL effectiveness. Their relation could be shown in the schematic model in Figure 5.7:

![Figure 5.7. The schematic model of PBL effectiveness with learner engagement as parameter.](image)

In this model, the horizontal axis, LE1, LE2, LE3, …LEn, represents the degrees of learner engagement which, as parameter of PBL, also represents the different types of PBL. The vertical axis represents PBL effectiveness. By examining the relation between the degrees of learner engagement and effectiveness values, the optimal degrees of learner engagement, that is, the optimal type of PBL can be determined and the trend of PBL effectiveness can be identified.

5.3 CONCLUSIONS

In this chapter, considering the complex nature of learning with various factors involved, a schematic model of general teaching and learning was built, and the role of different nature of parameters (i.e. sensitive and insensitive) and different quantity of parameters were analyzed in differentiating different teaching and learning approaches as well as the different types of the same teaching and learning approach. The analysis indicated that identifying suitable parameters of PBL is the core issue in studying the effectiveness of PBL. Accordingly, based on educational theories, i.e. self-directed learning theory and learner engagement theory, two key parameters of PBL were identified, and two schematic model of PBL effectiveness were proposed. What need to be done further is to verify the two schematic models.
Chapter 6.

A PILOT STUDY FOR VERIFYING THE THEORETICAL MODEL OF PBL EFFECTIVENESS

In this chapter a pilot study of the effectiveness of design project modules were introduced. The aim of the pilot study was to check the possibility of the existence of the relation between the identified parameters and PBL effectiveness. For simplicity, only SDL was chosen as the parameter of PBL in this study. The results indicated that a certain trend exists between SDL and corresponding improvement in design project modules, thus it is possible to identify a relative optimal PBL approach. This pilot study paved the way to the verifying of the feasibility of the PBL effectiveness model through a survey at a wider scale conducted subsequently.

6.1 PURPOSE OF THE PILOT STUDY

Before the test of the feasibility of the PBL effectiveness model, a pilot study was conducted to see the possible trend of relation between SDL and corresponding improvement in real-time PBL approaches.

6.2 METHODOLOGY

A pilot questionnaire was designed on the effectiveness of design project modules in order to do the quantitative measurement to see the trend of the relation between SDL and corresponding improvement. The questionnaire included four main sections:

First, information on students past design project experience;

Second, the amount of time students spent on their design project modules in the form of percentage ranging from 0% ~100%, including 1) listening to lectures, 2) being supervised in groups and individually, 3) self-directed group work, 4) self-directed individual work;

Third, students’ self assessment on their achievement in the design modules, totaling 12 statements (eg, the ability to define problems in design project), in the form of 7-point Likert scale ranging from “0=no improvement at all” to “6=total improvement”;

Forth, the extent of satisfaction in a 7-point Likert scale ranging from “0=completely unsatisfied” to “6=completely satisfied”.

Interviews were also conducted after the questionnaire administration as a supplement to the understanding of the results.
6.3 PARTICIPANTS

Three design project modules at Loughborough University in central England were chosen to collect the data at the beginning of their second semester in February 2008, one third year module and one forth year module from the Department of Civil and Building Engineering and one forth year module from the Department of Aeronautical and Automotive Engineering. The third year module used a past industrial project and the other two used real projects provided by industry. All three project modules started in October 2007, with projects assigned at the beginning of the module and were to run for two semesters. All the three projects included parallel lectures, tutorials, students’ self-directed group work and individual study. A total of 83 students participated in the study. The detailed information was shown in the following table.

<table>
<thead>
<tr>
<th>Modules</th>
<th>Number of students</th>
<th>Academic year</th>
<th>Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module 1</td>
<td>35</td>
<td>3</td>
<td>Civil engineering</td>
</tr>
<tr>
<td>Module 2</td>
<td>18</td>
<td>4</td>
<td>Aeronautical engineering</td>
</tr>
<tr>
<td>Module 3</td>
<td>30</td>
<td>4</td>
<td>Civil engineering</td>
</tr>
</tbody>
</table>

6.4 DATA COLLECTION AND ANALYSIS

The questionnaire was administered during the first three weeks of the 2007/8 academic year with the help of the module teachers at the beginning of their modules. The staff interviews were conducted with the same teachers within a few days of the administration of the questionnaires. SPSS 16.0 was used to analyze the data, including

1) ANOVA analysis to examine the differences in the amount of self-directed learning time and student achievement between design project modules
2) Factor analysis to find out the categories of students achievement.

6.5 FINDINGS

6.5.1 Time Allocation in Three Design Project Modules

![Time allocation in three modules](image)

Table 6.2. Means for time allocation in three modules.

<table>
<thead>
<tr>
<th>Modules</th>
<th>Time for lecture</th>
<th>Time for supervision</th>
<th>Time for group work</th>
<th>Time for individual work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module 1</td>
<td>28.18%</td>
<td>11.18%</td>
<td>30.29%</td>
<td>29.18%</td>
</tr>
<tr>
<td>Module 2</td>
<td>17.25%</td>
<td>14.75%</td>
<td>40.58%</td>
<td>26.53%</td>
</tr>
<tr>
<td>Module 3</td>
<td>12.00%</td>
<td>9.21%</td>
<td>46.45%</td>
<td>31.34%</td>
</tr>
</tbody>
</table>

A pilot study of experiment
Figure 6.1 shows the time allocation by students in the 3 design project modules including time for their supervised learning (including listening to lectures and being supervised individually and in groups) and self-directed learning (including both group work and individual work). Table 6.2 shows the means of the amount of time allocation corresponding to the graph in Figure 6.1. It can be seen that, as expected in all the three modules, the time proportion for self-directed group work accounts for the most part of students’ total time in design modules, with the time for self-directed individual study running second, time for listening to lectures being the third and students’ time for being supervised ranking the last.

Table 6.3. The comparison of the amount of time allocation between three design modules.

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>(I) Different modules</th>
<th>(J) Different modules</th>
<th>Mean difference (I-J)</th>
<th>Std. Error</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time proportion of lecture</td>
<td>Module 1 Module 2</td>
<td>Module 3 Module 3</td>
<td>10.926(*)</td>
<td>2.858</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>16.176(*)</td>
<td>2.478</td>
<td>.000</td>
</tr>
<tr>
<td>Time proportion of group work</td>
<td>Module 2 Module 3</td>
<td></td>
<td>6.250</td>
<td>2.942</td>
<td>.210</td>
</tr>
<tr>
<td></td>
<td>Module 1 Module 2</td>
<td>Module 3 Module 3</td>
<td>-10.289(*)</td>
<td>4.091</td>
<td>.048</td>
</tr>
<tr>
<td></td>
<td>Module 1 Module 2</td>
<td>Module 3 Module 3</td>
<td>-16.154(*)</td>
<td>3.548</td>
<td>.000</td>
</tr>
</tbody>
</table>

* The mean difference is significant at the .05 level.

In Table 6.3, the difference in the amount of time between three modules by SPSS showed that in students’ amount of time for listening to lectures, there is significant difference (p<.05) between module 1 and module 2, and module 1 and module 3 respectively; no significant difference was found between module 2 and module 3 in this aspect. The same pattern of significant difference can be found in the amount of time for group work (p<.05).

Figure 6.2. Time proportion of SDL in three modules.

Table 6.4. Means for the amount of SDL in 3 modules.

<table>
<thead>
<tr>
<th>Different modules</th>
<th>Time for group work</th>
<th>Time for individual work</th>
<th>Total time for self directed learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module 1</td>
<td>30.29%</td>
<td>29.18%</td>
<td>59.47%</td>
</tr>
<tr>
<td>Module 2</td>
<td>40.58%</td>
<td>26.53%</td>
<td>67.11%</td>
</tr>
<tr>
<td>Module 3</td>
<td>46.45%</td>
<td>31.34%</td>
<td>77.79%</td>
</tr>
</tbody>
</table>
Figure 6.2 shows the average amount of students’ time for self-directed learning (including both group work and individual work) in three modules, the exact means for the amount of students’ time for self-directed learning were shown in Table 6.4 An ascending trend can be seen in the three modules, with module 1 ranking the lowest (60%) and module-3 the highest (78%) and, as shown in Table 6.5, the ANOVA analysis showed that significant difference can be found between module 1 and module 3 and between module 2 and module 3 (p<.025).

Table 6.5. The comparison of students’ time for SDL between 3 modules.

<table>
<thead>
<tr>
<th>(I) Different modules</th>
<th>(J) Different modules</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module 1</td>
<td>module 2</td>
<td>-7.696</td>
<td>3.614</td>
<td>.110</td>
</tr>
<tr>
<td>Module 2</td>
<td>module 3</td>
<td>-18.323(*)</td>
<td>3.134</td>
<td>.000</td>
</tr>
</tbody>
</table>

* The mean difference is significant at the .05 level.

6.5.2 Effectiveness of Three Design Project Modules

Figure 6.3 shows the satisfaction expressed by students in the three modules. Not much difference can be found in the 3 modules (ranging from 4.4 to 4.65), with module 2 ranking the highest and module 1 the lowest. It shows that students are generally satisfied with the teaching and learning in the modules (4 representing slight satisfaction and 5 representing satisfaction).

Figure 6.4 shows the means of the general improvement from the twelve statements in the questionnaire on student self-assessed improvement achieved in their design project modules. The twelve statements were graded in a 7 point Likert scale ranging from “0=no improvement at all” to “6=total improvement”. It can be seen that there is an obvious (yet not significant) difference between module 2 and the other two, with the improvement of module 2 falling in the scale point 4 (representing improvement) and the other two both 3 (representing slight improvement).
A pilot study of experiment

To have an in-depth understanding of students’ improvement in the PBL design modules, factor analysis was conducted through SPSS and two categories of effectiveness were extracted from the 12 statements on student self-assessed improvement, with one category falling into the design ability. (including formulating design problems, evaluating others’ design concepts, etc) and the other transferable skills (including managing time effectively, working effectively as team members, etc). The two categories were shown respectively in Figure 6.5 and Figure 6.6. It can be seen that the improvement in design ability (category 1) is higher than that in transferable skills (category 2). Again module 2 ranks the highest in the improvement in these two categories of student improvement. The difference in the improvement did not reach the significant difference.

6.6 DISCUSSIONS AND IMPLICATIONS

6.6.1 The Relation between SDL and Improvement

It can be seen in figure 6.1. that the proportions of time spent on self-directed learning by the students in the three design project modules are clearly different, with corresponding different degrees of student self-assessed improvement. (as shown in Figure 6.1) . The result indicates that different proportions of students’ self-directed learning time used to represent the different types of PBL can lead to different degrees of student improvement, which implies that there would possibly be an optimal proportion of students’ self-directed time in the PBL process which may lead to the best improvement. (Here in this study, the module with 68% self-directed learning time seems to be the optimal one). Thus with the trend shown in this study, it is possible that a relative optimal type of PBL can be determined when a general trend can be found by studying more project modules.

6.6.2 Student Time Allocation in PBL

PBL is characteristic of group work and student self-directed learning. This is clearly shown in students’ time spent on both the two distinct learning activities in this study (shown in Figure 6.2 and Figure 6.3). The point we need to pay attention to is that despite the significant difference in the proportion of lectures in the three modules, the proportions of students’ supervision from teachers in the three modules are similar and rank the lowest in the proportion.
of time spent by the students. This might be because the modules chosen in this study are in the third and final year and students are, by this time, accustomed to working much more independently from staff than those in the first or second year. On the other hand, the findings indicate that much of the learning in PBL is beyond teacher’s direct control and the true amount of student self-directed learning work is important for their learning achievement in PBL.

6.6.3 Categories of Student Learning Improvement
In this short study two categories of student learning were identified: design ability and transferable skills, both of which are important for engineering graduates. Within the proportions of students’ self-directed learning time in this study, the students in this study ranked their learning in design ability greater than transferable skills (as shown in Figure 6.5). Transferable skills are more related with life long learning and help students to learn how to learn. The lower point of transferable skills might result from students’ relatively limited self-directed learning ability in PBL and more guidance from teachers in this aspect seems to be required. Another possible reason for the small improvement of transferable skills might be because students perceived that they had a relatively higher starting point of these skills compared with design ability /skills, because quite a number of students had some engineering experience from previous formal modules or work placement or Sandwich placement. It would be interesting to make an in-depth study to study the first and second year students’ corresponding aspects of improvement and compare the difference with the findings in this study.

6.6.4 Student Satisfaction with PBL
From the findings it can be seen that most of the students in the three modules are satisfied but not over-enthusiastic with their learning experience in PBL, even including those students who did not achieve much improvement. This exactly reflects one of the advantages of PBL, that is, stimulate students’ interest and motivation from the “learning by doing” approach. As this research study develops, it will be important to pay particular attention circumstances where students claim low satisfaction and determine the reasons and trends for it.

6.7. CONCLUSIONS
In this study, we aimed to see the possible trend of the relation between SDL and student improvement in the real-time PBL approaches. A pilot study was conducted in three design project modules and the result showed certain trend existed in the relation between SDL and student improvement in real-time PBL, indicating that a relatively optimal PBL approach can be determined.
Chapter 7.

THE MODEL OF PBL EFFECTIVENESS
IN ENGINEERING DESIGN

In previous two chapters we have respectively discussed PBL effectiveness from the perspectives of engineering lectures and graduates, and parameters of teaching and learning and the determination of parameters of PBL – self-directed learning and learner engagement. This chapter, then, is aimed to study what relation is like between the determined parameters of PBL and the PBL effectiveness.

To date, there has been much research on the relation between self-directed learning, learner engagement and PBL effectiveness, and the relation between learner engagement learning and PBL effectiveness. Most research focused on either the linear relation between a certain parameter of PBL and its effectiveness or the linear interaction of various parameters within PBL. From these research we could know what parameters affect PBL effectiveness and in what aspects, but it is still unknown such effects are to what extent and why. That is, no research has ever studied what the trends between these parameters and PBL effectiveness are like. This chapter was to deal with this issue by building a model of PBL effectiveness through experiment.

7.1 PURPOSE OF THE EXPERIMENT

The purpose of this experiment is twofold:

First and foremost, it is aimed to find out the relation between the two key parameters of PBL, namely, self-directed learning and learner engagement, and the effectiveness of PBL.

Second, it is aimed to find out the effects of influencing factors on the model of PBL effectiveness.
7.2 METHODOLOGY

7.2.1 Reasons for Using Student Self-report Survey in this Experiment

The experiment was conducted with the instrument of student self-report survey. The reasons for using self-report survey is two fold:

First, using student self-report survey to assess the quality of undergraduate education is common place mainly because it is comparatively not expensive and easy to develop and administer (Kuh, 2001, Carini et al., 2006). Well-crafted survey can “provide insight into student experience that other sources of information cannot, such as estimates of ability to interact effectively with others on an individual basis or in small groups, and the degree to which one’s values and ethics developed since college” (Carini et al., 2006). Besides, for many indicators, such as how students use their time, student survey is often the only meaningful source of data (Kuh, 2001).

Second, to meet the requirement of the purpose of this research. In this research, to find out the relation between the two parameters of PBL, self-directed learning and learner engagement, and the effectiveness of PBL, it is necessary to know the amount of time students spent on their self-directed learning and the degree of students’ engagement in their learning activities in the whole course of their design project modules/courses. It should be noted that much of students’ self-directed learning and students’ mental/psychological engagement in their learning activities is beyond researchers’ direct observation. On the other hand, field observation and interviews also limit the number of students under study, which is not suitable for this experiment because a relatively large sum of data is expected to collect in order to find out the trend in the relation between parameters of PBL and PBL effectiveness. Therefore, the self-report survey is a suitable method in this research which can satisfy the purpose of the experiment.

7.2.2 Validity and Reliability Issues of Student Self-report Survey

As a traditional way of research method, the validity and reliability of student self-report survey has been thoroughly explored. Generally, there are three main factors affecting its validity and reliability: 1) the inability of the respondent to provide accurate information; 2)
unwillingness of the respondent to provide truthful information; 3) halo effect, here it refers to the possibility of students inflating certain aspects of their behavior or performance, such as grades, achievements, level of learning efforts, etc. (Kuh, 2001).

Therefore, a valid survey should generally meet the following five conditions: 1) the information requested is known to the respondents; 2) the questions are phrased clearly and ambiguously; 3) the questions refer to recent activities; 4) the respondents think the questions merit a serious and thoughtful response; and 5) answering the questions does not threaten, embarrass or violate the privacy of the respondent or encourage the respondent to respond in a socially desirable way (Kuh, 2001).

With all this in mind, the questionnaire designed in this research strictly followed the requirements of a valid survey. In addition, mathematical/statistical measures (i.e. moving average) were taken to ensure the accuracy of the self-report data in this experiment (Details please see section 7.3.3.2 Validity and reliability of the questionnaire).

7.2.3 Construction of the Questionnaire in This Experiment

7.2.3.1 Structure and Content of the Questionnaire

The questionnaire used in the survey was composed of six main sections:

Section 1: student background information including gender, degree programme, and previous industrial experience. This section was designed in order to know some basic background information of the students participated in, and also to find out what effects of students’ previous industrial experience might have on their PBL effectiveness.

Section 2: individual student’s percentage of time spent on each learning activity in PBL. This section was designed based on self-directed learning theory in order to find out the amount of self-directed learning time students spent in their engineering design projects. The learning activities listed in the questionnaire aimed to cover all the possible learning activities by students in their engineering design projects, including listening to lectures, team and individual
supervision, team and individual independent learning, and other informal ways of learning. Details of the learning activities were shown in Table 7.1 below:

<table>
<thead>
<tr>
<th>Activities</th>
<th>Approximate proportion of Actual time spent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a  Listening to lectures</td>
<td>%</td>
</tr>
<tr>
<td>b  Being supervised by or discussing with teachers (lectures, tutors,</td>
<td>%</td>
</tr>
<tr>
<td>mentors or industrial professionals, etc.) in groups both in and</td>
<td></td>
</tr>
<tr>
<td>outside of class</td>
<td></td>
</tr>
<tr>
<td>c  Discussing on your own with teachers (lectures, tutors, mentors or</td>
<td>%</td>
</tr>
<tr>
<td>industrial professionals, etc.) in groups both in and outside of class</td>
<td></td>
</tr>
<tr>
<td>d  Studying/working in groups without supervision from teachers (</td>
<td>%</td>
</tr>
<tr>
<td>lectures, tutors, mentors or industrial professionals, etc.) in</td>
<td></td>
</tr>
<tr>
<td>groups both in and outside of class</td>
<td></td>
</tr>
<tr>
<td>e  Individual private study (eg: searching literature, reading, writing</td>
<td>%</td>
</tr>
<tr>
<td>reports, preparing presentations or exams, etc.)</td>
<td></td>
</tr>
<tr>
<td>f  Other (eg: discussing with peers by email, informal chatting with</td>
<td>%</td>
</tr>
<tr>
<td>peers or friends, etc.)</td>
<td></td>
</tr>
</tbody>
</table>

Total proportion (a+b+c+d+e+f) should add up to 100%

It should be noted that in the questionnaire, instead of asking students the exact hours they spent on each activity, they were required to provide the approximate percentage of time they spent on each activity against the total amount of time they spent in the whole design project module/course. The reason for using percentage of time is that the lengths of design projects vary from one to one, thus there is no common basis to compare the time by using hours, while the percentage of time can make it possible to compare SDL time in design projects with different lengths.

Because these activities listed in the questionnaire covered all the learning activities in any certain design project, the total sum of the percentage of time for these activities, that is, the
percentage of time from item a to item f, should be added up to 100%. Based on self-directed learning theory which is characteristic of students’ initiative in their learning, of all the learning activities, the items c, d, e and f constitute the total SDL time in PBL.

Section 3: Individual student’s perceptions of the degree of learner engagement in engineering design projects. This section was designed in order to find out the degree of individual student’s learner engagement. The items of learner engagement, totally nine, were designed based on learner engagement theory, reflecting different aspects of learner engagement. The degree of the learner engagement was shown in a 5 points Likert-type scale, from strongly agree to strongly disagree. The reason for using 5 points Likert-type scale is that it is the most reliable scale in most circumstances (Berdie, 1994). Details of the nine items of learner engagement were shown in Table 7.2:

Table 7.2 Items of learner engagement designed in the questionnaire.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>I like the way of team learning in the project.</td>
</tr>
<tr>
<td>b</td>
<td>I was active in the team discussion.</td>
</tr>
<tr>
<td>c</td>
<td>I took a leadership role in the teamwork.</td>
</tr>
<tr>
<td>d</td>
<td>I took more responsibility for the project than my teammates.</td>
</tr>
<tr>
<td>e</td>
<td>I was able to manage my time well in this project.</td>
</tr>
<tr>
<td>f</td>
<td>I often reflected on the progress of my work.</td>
</tr>
<tr>
<td>g</td>
<td>I had confidence to do my share of work well on my own.</td>
</tr>
<tr>
<td>h</td>
<td>I like meeting challenges in my study.</td>
</tr>
<tr>
<td>i</td>
<td>I prefer traditional teaching methods (eg: lectures + exams, etc.)</td>
</tr>
</tbody>
</table>

Section 4: individual student’s perception of improvement in design projects. This section was designed to find out the degree of learning effectiveness in PBL and its relation with students’ self-directed learning time and learner engagement.
There were 10 items of learning improvement in this section. These items were designed based on the requirements of Engineering Subject Benchmark Statement (QAA, 2006), UK SPEC (2004) and the findings of PBL effectiveness from this research (See chapter 4). Details of the items of learning improvement designed were shown Table 7.3 below:

Table 7.3 Items of learning improvement designed in the questionnaire.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Generating design concepts/solutions ability</td>
</tr>
<tr>
<td>b</td>
<td>Evaluating design concepts/solutions ability</td>
</tr>
<tr>
<td>c</td>
<td>Knowledge application ability (eg: engineering science, mathematics, etc.)</td>
</tr>
<tr>
<td>d</td>
<td>The ability to work effectively in a team</td>
</tr>
<tr>
<td>e</td>
<td>Time management skills</td>
</tr>
<tr>
<td>f</td>
<td>Independent learning ability</td>
</tr>
<tr>
<td>g</td>
<td>The ability to reflect on and monitor the project progress</td>
</tr>
<tr>
<td>h</td>
<td>The ability to deal with difficulties in your own share of work</td>
</tr>
<tr>
<td>i</td>
<td>The ability to deal with difficulties in the teamwork (eg: others work behind schedule; team conflicts, etc.)</td>
</tr>
<tr>
<td>j</td>
<td>Oral and/or written communication ability</td>
</tr>
</tbody>
</table>

The degree of the improvement was shown in an 11 points scale, from 0 to 10, with 0 representing *none improvement*, 5 representing *average improvement* and 10 *total improvement*. The reasons for using the 11 points scale are two fold: firstly, the improvement made by students might be subtle, so a more detailed scale was used to ensure that the subtle improvement can be detected; secondly, the range from 0-10 is intended to mirror the marking system at university which usually ranges from 0 - 100. Ranging the degree of improvement in this way, it is expected that students can better locate their improvement when answering the questionnaire.
Section 5: Individual student’s perception of the quality of design problems, lectures, tutorials and teamwork. This section was designed in order to find out the effects of these factors on PBL effectiveness.

These factors were selected because they represented two important aspects in the teaching and learning process – task and teacher. Design problem and teamwork are relevant to the aspect of task in that (design) problem is one key feature of PBL, which is the driver of all PBL learning activities; at the same time, most learning activities in PBL are usually team-based. Lecture and tutorial are relevant to the aspect of teacher. In PBL, teachers are supposed to play the role of facilitator and supporter, thus tutorial is important in PBL process. Lecture is a traditional teaching method. Some teachers have lectures parallel to design projects, others do not; so it is interesting to see what effect of lectures have on PBL effectiveness. Because of the above reasons, the four factors were determined in this section.

In the questionnaire, there were 3 items about design problem, 4 items about lecture, 3 items about tutorial, and 8 items about teamwork. These items were designed based on the research on engineering design project teaching and learning in literature review and on the researcher’s own tutorial and teamwork observation (See chapter 8). The degree of the quality of design problems, lectures, tutorials and teamwork was shown in a 5 points Likert-type scale, from strongly agree to strongly disagree. Details of these items were shown in Table 7.4:
### Table 7.4 Items of design problems, lecture, tutorial and teamwork designed in the questionnaire.

<table>
<thead>
<tr>
<th>Design problem</th>
<th>A. The design problem was interesting enough for me to put effort on it.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B. The design problem was challenging for my current knowledge and experience.</td>
</tr>
<tr>
<td></td>
<td>C. The design problem was closely related to my future career goals.</td>
</tr>
<tr>
<td>Lecture</td>
<td>A. The content of lectures facilitated my project work.</td>
</tr>
<tr>
<td></td>
<td>B. The lectures were useful to me in the engineering technical aspect.</td>
</tr>
<tr>
<td></td>
<td>C. The lectures were useful to me in the design knowledge and skills aspect.</td>
</tr>
<tr>
<td></td>
<td>D. The lectures were useful to me in the soft knowledge aspect (eg: teamwork skills, presentation skills, etc.).</td>
</tr>
<tr>
<td>Tutorial</td>
<td>A. The tutorials helped address my questions well.</td>
</tr>
<tr>
<td></td>
<td>B. The tutorials stimulated my critical thinking.</td>
</tr>
<tr>
<td></td>
<td>C. The tutorials facilitated my independent learning.</td>
</tr>
<tr>
<td>Team-work</td>
<td>A. Teamwork went well generally.</td>
</tr>
<tr>
<td></td>
<td>B. The task distribution in the team was fair.</td>
</tr>
<tr>
<td></td>
<td>C. Teammates completed their fair share of work on time.</td>
</tr>
<tr>
<td></td>
<td>D. The communication between team members was good.</td>
</tr>
<tr>
<td></td>
<td>E. The team meetings were efficient.</td>
</tr>
<tr>
<td></td>
<td>F. The discussion in team meetings was stimulating.</td>
</tr>
<tr>
<td></td>
<td>G. Team conflicts could be settled successfully.</td>
</tr>
<tr>
<td></td>
<td>H. I learned much from my teammates.</td>
</tr>
</tbody>
</table>

Section 6: The assessment methods used in design projects and individual student’s attitude to the assessment methods in PBL. This section was designed to know what effects the assessment methods and students’ attitude towards these methods have on PBL effectiveness. The assessment aspect was asked in the questionnaire because the assessment methods are generally different from that of traditional approach; in addition, it is still a controversial issue as to how to fairly and precisely assess student work in group design project. Therefore, although
assessment is not the focus of this experiment, two open questions were designed to get students’ opinions.

### 7.2.3.2 Validity and Reliability of the Questionnaire

**A. Validity of the questionnaire**

After the questionnaire was designed, it was examined by two engineering design experts and one engineering education expert to make sure that the questionnaire was clearly worded, well-defined, and had high face and content validity. Two statisticians were also consulted to ensure that the items were designed properly for the subsequent statistical analysis.

Another method to test the validity of the questionnaire is construct validity, which refers to whether a scale measures the theorized scientific construct that it purpose to measure (Wu, 2003). A common way to test construct validity is factor analysis (Wu, 2003; Kuh, 2001). In this research, the construct validity of the questionnaire was tested through factor analysis with SPSS 18.0.

First, the suitability of the items in the questionnaire was tested. This was done thorough KMO and Bartlett’s test. When the statistical value of Kaiser-Meyer-Olkin Measures of Sampling Adequacy (KMO) is above .80, the items in the questionnaire are suitable for factor analysis (Wu, 2003). The result of the KMO and Bartlett’s test of the items in this questionnaire was shown in the following table:

| Kaiser-Meyer-Olkin Measures of Sampling Adequacy | .823 |
| Bartlett Test of Sphericity | Approx. Chi-Square | 2189.596 |
| | df | 35 |
| | Sig. | .000 |

It can be seen in Table 7.5, the value of KMO is 0.823, which means that the items in the questionnaire were suitable for factor analysis.
Second, the factor analysis (SPSS 18.0) was applied to these items, with the extraction method of Principal Component Analysis and the rotation method of Varimax. Results of the factor analysis of the items in the questionnaire were shown in Table 7.6 below:

Table 7.6. Factor analysis of items in the questionnaire – design problems, lectures, tutorials, teamwork.

<table>
<thead>
<tr>
<th>Item</th>
<th>Teamwork</th>
<th>Lecture</th>
<th>Tutorial</th>
<th>Design problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>The communication between team members was good</td>
<td>.825</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The task distribution in the team was fair</td>
<td>.806</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teamwork went well generally</td>
<td>.806</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The team meetings were efficient</td>
<td>.785</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teammates completed their fair share of work on time</td>
<td>.782</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The discussion in team meetings was stimulating</td>
<td>.724</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I learned much from my teammates</td>
<td>.688</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Team conflicts could be settled successfully</td>
<td>.656</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The lectures were useful to me in the engineering technical aspect.</td>
<td>.856</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The content of lectures facilitated my project work.</td>
<td>.812</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The lectures were useful to me in the design knowledge and skills aspect.</td>
<td>.772</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The lectures were useful to me in the soft knowledge aspect (e.g. teamwork skills, presentation skills, etc.).</td>
<td>.666</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The tutorials stimulated my critical thinking.</td>
<td>.897</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The tutorials facilitated my independent learning.</td>
<td>.843</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The tutorials helped address my questions well.</td>
<td>.817</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The design problem was challenging for my current knowledge and experience</td>
<td></td>
<td></td>
<td></td>
<td>.743</td>
</tr>
<tr>
<td>The design problem was interesting enough for me to put effort on it.</td>
<td></td>
<td></td>
<td></td>
<td>.718</td>
</tr>
<tr>
<td>The design problem was closely related to my future career goals.</td>
<td></td>
<td></td>
<td></td>
<td>.574</td>
</tr>
<tr>
<td>(% Variance explained</td>
<td>19.276</td>
<td>10.620</td>
<td>8.951</td>
<td>6.806</td>
</tr>
</tbody>
</table>

The Model of PBL Effectiveness in Engineering Design
From Table 7.6, it can be seen that 4 clusters of items were discriminated, which corresponded to the categories of teamwork, lecture, tutorial and design problem designed in the questionnaire, indicating that these items are of good validity.

It should be noted that factor analysis of the items in learning engagement and learning improvement also indicated that these items were of good validity. However, they were not analyzed here. Their analysis was placed in the subsequent section 7.4.2.4 because it was relevant to the underlying properties within learning engagement and learning improvement.

B. Reliability of the questionnaire

The reliability of a questionnaire refers to the degree to which a set of items consistently measures the same thing across respondents and institutions. Reliability can be classified into “external reliability” and “internal reliability”. In multiple-item scale questionnaire like the one used in this research, the internal reliability is extremely important. In Likert-type scale, a common method to test the internal reliability is the Cronbach’s alpha coefficient (Wu, 2003). If the Cronbach’s alpha coefficient of the total items in a questionnaire is above .80, then this questionnaire is of good reliability (Bryman & Cramer, 1997). Besides the Cronbach’s alpha coefficient of the total items, that of the sub-total items in a questionnaire, such as the items in design problems, lectures, etc. respectively, also needs to be tested. The Cronbach’s alpha coefficients of the sub-total items should be above .70, which indicates that the reliability is good; when the Cronbach’s alpha coefficients of the sub-total items is between .60 and .70, the reliability is acceptable (Wu, 2003).

When checking the Cronbach’s alpha coefficient of the total items in this questionnaire, it should be noted that the number used to represent the 5-point Likert-type scale in sections of design problem, lecture, tutorial, teamwork and learning engagement (i.e. 1 = strongly agree, 2 = agree, 3 = neither agree or disagree, 4 = disagree, 5 = strongly disagree) is inconsistent with that used to represent the 11-point likert-type scale in the section of learning improvement (0 = none improvement, 5 = average improvement, 10 = total improvement). In the former sections the bigger number represents negative trend (i.e. decreasing agreement), while in the latter
section the bigger number represents positive trend (i.e. increasing improvement). Thus, when calculating the Cronbach’s alpha coefficient, the inconsistency of the number was corrected by changing the original number representing the 11-point Likert-type scale to the opposite way, that is, 0 = total improvement, 5 = average improvement, 10 = none improvement. In this way, the numbers in the Likert-type scale in the questionnaire was consistent and the value of the Cronbach’s alpha coefficient of the total items can be calculated.

Similarly, the number used to represent the 5-point Likert-type scale in the 9th item of learner engagement in the questionnaire, i.e., I prefer traditionally teaching methods (eg: lectures + exams, is opposite to that of the other eight items. In the former item, the small value indicates the low degree of learner engagement, and the great value indicates the high degree of learner engagement. This is just the opposite of the other eight items. Thus the order of the original 5 points scale was reversed in the process of data analysis in the way as the following: 5 = Strongly agree; 4 = Agree; 3 = Neither agree or disagree; 2 = Disagree; 1 = Strongly disagree.

After all these were done, the Cronbach’s alpha coefficients of the total items and sub-total items in this questionnaire were calculated by using SPSS 18.0 and the values were shown in Table 7.7 and 7.8 respectively:

<table>
<thead>
<tr>
<th>Cronbach's Alpha</th>
<th>Cronbach’s Alpha Alpha-Based on Standardized Items</th>
<th>N of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>.897</td>
<td>.893</td>
<td>37</td>
</tr>
</tbody>
</table>

The Model of PBL Effectiveness in Engineering Design
Table 7.8. Reliability statistics of the questionnaire – sub-total items.

<table>
<thead>
<tr>
<th>Sub-total items</th>
<th>Cronbach's Alpha</th>
<th>Cronbach’s Alpha Based on Standardized Items</th>
<th>N of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design problem</td>
<td>.591</td>
<td>.614</td>
<td>3</td>
</tr>
<tr>
<td>Lecture</td>
<td>.811</td>
<td>.826</td>
<td>4</td>
</tr>
<tr>
<td>Tutorial</td>
<td>.879</td>
<td>.879</td>
<td>3</td>
</tr>
<tr>
<td>Teamwork</td>
<td>.889</td>
<td>.891</td>
<td>8</td>
</tr>
<tr>
<td>Learner engagement</td>
<td>.778</td>
<td>.785</td>
<td>9</td>
</tr>
<tr>
<td>Learning improvement</td>
<td>.885</td>
<td>.887</td>
<td>10</td>
</tr>
</tbody>
</table>

It can be seen from Table 7.7 that the Cronbach’s alpha coefficient of the total items in this questionnaire is above .80, indicating that the questionnaire is of good reliability. In Table 7.8, it can be found that the Cronbach’s alpha coefficients of most sub-total items are above .70, indicating that the reliability of most of these sub-total items is good. The exception is the item of design problem, the Cronbach’s alpha coefficient of which is below 0.6, indicating that its reliability is not good. Thus, a further analysis was made in the design problem to check if the Cronbach’s alpha coefficient could be increased if any item related to design problem is deleted. The statistical information was shown in Table 7.8.1:

Table 7.8.1. The statistical information of the Cronbach’s alpha coefficient of design problem if item deleted.

<table>
<thead>
<tr>
<th>Items related to design problem</th>
<th>Cronbach's Alpha if Item Deleted</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. The design problem was interesting enough for me to put effort on it.</td>
<td>.323</td>
</tr>
<tr>
<td>b. The design problem was challenging for my current knowledge and experience</td>
<td>.525</td>
</tr>
<tr>
<td>c. The design problem was closely related to my future career goals.</td>
<td>.634</td>
</tr>
</tbody>
</table>

It can be seen from Table 7.8.1 that among the three items related to design problem, if the item a and b were deleted, the Cronbach’s alpha coefficient of design problem would be decreased and became smaller than the original; whereas if the item c was deleted, the Cronbach’s alpha coefficient of design problem would be increased and became greater than 6.0, which indicates that its reliability is acceptable for sub-total items (Wu, 2003).
Considering the sub-total item of design problem did not influence the reliability of the whole questionnaire, the original items related to design problem were kept in the questionnaire. However, in the data analysis, the negative influence of item c in design problem should be taken into consideration and needed to be deleted if necessary.

7.3. DATA COLLECTION

7.3.1 Participants

The participants of the survey were engineering undergraduates having taken part in group design projects in their modules/courses at university. The participants were chosen randomly from UK universities, based on their willingness to cooperate with the researcher.

7.3.2 Data Collection Procedures

The questionnaire was administered by the end of the spring semester in 2009 in 5 UK universities, including Loughborough University, Imperial College of London, University of Birmingham, University of Nottingham and University of Manchester. Totally 5 engineering degree programmes were covered, namely, Civil engineering, Mechanical engineering, Aeronautic engineering, Chemical engineering and Materials engineering. The questionnaire was administered in both paper-based and computer-based forms (The online version of the survey can be reached at the address http://www.survey.lboro.ac.uk/sdltpbl). Totally 331 valid questionnaire were collected from year 1 to year 4 students, among which there are 175 in year 1, 68 in year 2 and 88 in year 3 and year 4 (Because the numbers of students in year 3 and year 4 were small, they were combined together). The summary of the questionnaire distribution in universities, degree programmes, people who helped with the questionnaire administration, academic years and number of responses were shown in Table 7.9:
Table 7.9. The summary of the questionnaire distribution.

<table>
<thead>
<tr>
<th>Questionnaire form</th>
<th>University</th>
<th>Degree programme</th>
<th>Module lecturer</th>
<th>Academic year</th>
<th>Number of response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper-based</td>
<td>Loughborough University</td>
<td>Mechanical engineering</td>
<td>Dr. Peter Willmot</td>
<td>Year 1</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aeronautical engineering</td>
<td>Mr. Tearle</td>
<td>Year 1</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>Imperial College London</td>
<td>Civil engineering</td>
<td>Dr. Ahearn &amp; her colleagues</td>
<td>Year 1</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Year 2</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Year 3</td>
<td>30</td>
</tr>
<tr>
<td>Computer-based</td>
<td>Loughborough University</td>
<td>Mechanical engineering</td>
<td>Dr. Peter Willmot</td>
<td>Year 1</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Civil and building engineering</td>
<td>Dr. Peter Demian</td>
<td>Year 2</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Year 3</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aeronautical engineering</td>
<td>Dr. Page</td>
<td>Year 4</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aeronautical engineering</td>
<td>Dr. Chen</td>
<td>Year 3</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemical engineering</td>
<td>Dr. Tarleton</td>
<td>Year 3</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Materials engineering</td>
<td>Dr. Wu</td>
<td>Year 2</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Materials engineering</td>
<td>Professor Thomson</td>
<td>Year 3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>University of Birmingham</td>
<td>Chemical engineering</td>
<td>Dr. Robbins</td>
<td>Year 4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>University of Nottingham</td>
<td>Civil engineering</td>
<td>Dr. Mawdesley</td>
<td>Year 1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>University of Manchester</td>
<td>Civil engineering</td>
<td>Mrs. Hiley</td>
<td>Year 2</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>331</td>
</tr>
</tbody>
</table>

7.4 DATA ANALYSIS

7.4.1 Data Analysis Tools

In this experiment, the statistics software SPSS 18.0, Origin 6.0 Professional, and Fortran Power Station 4.0 were used in analyzing the data in the following four aspects: 1) descriptive statistics and comparison (SPSS 18.0); 2) factor analysis (SPSS 18.0); 3) moving average analysis (Fortran Power Station 4.0); 4) polynomial fit analysis (Origin 6.0 professional)
7.4.2 Data Analysis Procedures

7.4.2.1 Analyzing the Relation between Self-directed Learning Time and PBL Effectiveness

Step 1 Analyzing the data of SDL time as time series

A time series is a collection of observations made sequentially through time (Chatfield, 2004, p1). In this experiment, a collection of effectiveness values were collected which spread sequentially along SDL time ranging from 0% to 100%. Thus, the data of SDL time can be taken as time series in the process of its analysis.

There are two types of time series: one is continuous when “observations are made continuously through time”; the other is discrete when “observations are taken only at specific times, usually equally spaced” (Chatfield, 2004, p5). In this experiment, the effectiveness values were collected at SDL times reported by students, in which a random element involved because the reported SDL times could not be ensured to be continuous or equally spaced.

The time series like the data of SDL time in this experiment was called stochastic process, or random process, which statistically refers to “a statistical phenomenon that evolves in time according to probabilistic laws”, and is mathematically defined as “a collection of random variables that are ordered in time and defined at a set of time points, which may be continuous or discrete” (Chatfield, 2004, p33). Moving average is the most commonly-used technique to estimate the trend of a time series and to reduce stochastic noise (Fan & Yao, 2003; Chatfield, 2004).

Step 2 Mathematical explanation of the moving average applied in this experiment

Moving average is a term in statistics used to analyze a set of data points by creating a series of averages of different subsets of the full data set. There can be many different forms of moving average (Chatfield, 2004, p17). The form of moving average used in this experiment was explained from the perspective of mathematics as follows:
Given a function \( f(x) \) (see Fig. 7.1) satisfying the condition

\[
\int_{-\infty}^{\infty} f(x) \, dx = 1, \tag{1}
\]

the average of data at the point \( \xi \) is defined as

\[
\bar{D}(\xi) = \int_{-\infty}^{\infty} D(x) f(x - \xi) \, dx \tag{2}
\]

where \( D(x) \) is the data at a point \( x \).

Particularly, function \( f(x) \) is chosen as follows in our numerical study

\[
f(x - \xi) = \begin{cases} 
1/\Delta t & \text{if } \xi - \Delta t/2 \leq x \leq \xi + \Delta t/2 \\
0 & \text{if } x < \xi - \Delta t/2 \text{ or } x > \xi + \Delta t/2
\end{cases} \tag{3}
\]

which is shown in Fig. 7.2.

Substituting eqn.(3) into eqn.(2) yields

\[
\bar{D}(\xi) = \frac{1}{\Delta t} \int_{\xi - \Delta t/2}^{\xi + \Delta t/2} D(x) \, dx. \tag{4}
\]

Figure 7.1. Basic mathematical model of parameter \( x \).

Figure 7.2. Moving average of parameter \( x \).
The discrete format of eqn. (4) is taken as
\[
\bar{D}(\xi_j) = \frac{1}{N_j} \sum \mathcal{D}(x_i) \quad \text{for} \quad \xi - \frac{N}{2} \leq x_i \leq \xi + \frac{N}{2}
\]  
(5)

where \( N_j \) is the number of data points located inside the interval \([\xi - \frac{N}{2}, \xi + \frac{N}{2}]\).

Step 3 Concrete procedures of moving average in this experiment

Based on the form of moving average explained above, the moving average applied in this experiment was as follows:

Suppose the number of all the data points is \( N \) as shown in Figure 7.3. We choose a local time interval, the length of which is represented as \( DT \). Then we count the number of data points within this local time interval and average all these data points, and we can get the effectiveness value at the central point of this local time interval. Then the central point moves forward a certain length, represented as \( DS \), and repeat the above averaging operation. Then the central point moves forward the length of \( DS \) again, and the averaging operation is repeated again. In this way, the central point keeps moving forward the length of \( DS \) and the averaging operation keeps repeated until the central point moves outside of these \( N \) data points. In doing so, a moving average curve is traced. A similar way of moving average was described by Fan and Yao (2003, p217).

Step 4 Time intervals and moving-forward lengths of the moving average in this experiment

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The question of what is the best interval of observation is to be decided in the light of the circumstances of the individual case (Kendall, Stuart and Ord, 1983, p428). Thus, in this experiment, the local time interval and the moving forward length can be adjustable to fit for the circumstances of this experiment.

In addition, in the process of data analysis, the following two points were taken into consideration:

1) The amount of data points in each local time interval should be enough to form teams and represent types of PBL. In this experiment, the data points in each local time interval were at least no less than 5;
2) The amount of central points (which represented types of PBL) should not be too few for significant curve fitting analysis.

Accordingly, in this experiment, generally moving average of 5 and 10 were chosen to apply. Moving average of 5 referred to local time interval of 5 and moving forward length of 5, i.e. DT=5, DS=5; Moving average of 10 referred to local time interval of 10 and moving forward length of 5 and/or 10, i.e. DT=10, DS=5 and/or DT=10, DS=10. The underlying principle for doing more than one moving average in this experiment was that “the choice of a trend line is to some extent a matter of judgment in light of the purpose we have in mind”, and “it is often necessary to fit several trends and to choose from among them the one which appears to answer the purpose best” (Kendall, Stuart and Ord, 1983, p477).

Step 5 Designing programme for the calculation of moving average in this experiment

Based on the mechanism described above, a programme was designed for calculating the moving average in this experiment, as shown in Table 7.10.
Table 7.10. Programme for moving average by Fortran Power Station 4.0.

```
COMMON Z(20000)
DIMENSION X(10000),Y(10000),Xave(10000),Yave(10000)
OPEN(UNIT=1,FILE='input.TXT',STATUS='OLD')
OPEN(UNIT=5,FILE='output.xls',STATUS='NEW')
N=?
DT=?
DS=?
READ(1,*) (Z(I),I=1,2*N)

DO 6 I=1,N
   X(I)=Z(I)
   Y(I)=Z(I+N)
6 CONTINUE

Tstart=0.0
Tend=Tstart+DT
Nave=1
8 CONTINUE

Nsum=0
Ysum=0.0
DO 7 I=1,N
   IF(X(I).GE.Tstart.AND.X(I).LE.Tend) THEN
      Nsum=Nsum+1
      Ysum=Ysum+Y(I)
   ENDIF
7 CONTINUE
```
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\[
X_{ave}(Nave) = T_{start} + DT/2.0
\]

IF(Nsum.NE.0) THEN
Yave(Nave) = Ysum/Nsum
ELSE
Yave(Nave) = 0.0
ENDIF

IF(Nsum.GT.3) THEN
Yave(Nave) = Ysum/Nsum
ELSE
Yave(Nave) = 0.0
ENDIF

IF(Tend.GE.100.0) THEN
GOTO 9
ELSE
Nave = Nave + 1
Tstart = Tstart + DS
Tend = Tstart + DT
GOTO 8
ENDIF

9 CONTINUE

WRITE(5,*) '==========X=========='
DO 10 I=1,Nave
10 WRITE(5,*) Xave(I)
WRITE(5,*) '==========Y=========='
DO 11 I=1,Nave
11 WRITE(5,*) Yave(I)
In the programme shown in Table 7.10, N represents the amount of all the data points in a time series; DT represents the length of local time interval; DS represents the moving-forward length. All the calculations of moving average were conducted with the software instrument Fortran Power Station 4.0 based on this programme.

Step 6 Trend curve fitting in this experiment

After the completion of the calculations of the moving average, the trend curve fitting was conducted. There are many ways of curve fitting, including polynomial, exponential, logistic and Gompertz curves (Chatfield, 2004, p16). In this experiment, polynomial curve fitting was applied in order to identify the optimal SDL time for the PBL effectiveness. All the analysis of the polynomial curve fitting was conducted by using software Origin 6.0 professional.

The goodness-of-fit, that is, how well a set of observations are fit, was tested with coefficient of determination (COD) R-Square, and the significance of polynomial curve fitting was tested with the F value and its corresponding P value (Pr > F) (Dowdy, Wearden and Chilko, 2004, p453).

With the procedures from step 1 to step 6 described above, the relation between PBL effectiveness and SDL time was identified and the SDL time for the optimal PBL effectiveness was determined.

7.4.2.2 Analyzing the Relation between Learner Engagement and PBL Effectiveness

Step 1 Quantifying the data of learner engagement

In the section of learner engagement in the questionnaire, students’ perceptions of their degrees of learning engagement were asked with the 5 points Likert type scale, including Strongly agree, Agree, Neither agree or disagree, Disagree, and Strongly disagree. If these 5 points scale was quantified in a continuum, then the degree of learner engagement can be quantified in the...
following way:

1= Strongly agree; 2= Agree; 3= Neither agree or disagree; 4= Disagree; 5= Strongly disagree.

There are totally 9 items in the section of learner engagement. After quantification, an individual student’s learner engagement degree should range from 1 to 45. The smaller the value is, the higher degree of learner engagement an individual student would have; the greater the value is, the lower degree of learner engagement an individual student would have.

It should be noted that the meaning of the 9th item of learner engagement in the questionnaire, i.e., I prefer traditionally teaching methods (eg: lectures + exams, is opposite to that of the other eight items in that the former is about the degree of engagement in traditional approaches, whereas the latter are about the degree of engagement in PBL. That is to say, in the 9th item, the small value indicates the low degree of learner engagement, and the great value indicates the high degree of learner engagement. This is just the opposite of the other eight items. Thus the order of the original 5 points scale was reversed in the process of data analysis in the way as the following:

5= Strongly agree; 4= Agree; 3= Neither agree or disagree; 2= Disagree; 1= Strongly disagree.

Then, the general learner engagement as the parameter of PBL in this experiment was quantified.

Step 2 Applying moving average in analyzing the relation between learner engagement and PBL effectiveness

Moving average was also applied to the analysis of the relation between learner engagement and PBL effectiveness, with learner engagement as a parameter. The procedures of the moving average here were basically following those in the analysis of the relation between SDL time and PBL effectiveness. The only difference was in the length of the local interval and the moving-forward length, with the former being 1 and 2, and the latter 1 and 2 respectively.

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7.4.2.3 Analyzing the Relation between Categorized SDL Time, Learning Engagement and PBL Effectiveness

Step 1 Categories of SDL time

Among the four items of SDL time designed in the questionnaire, two of which were related with private SDL, including item c, *discussing on your own with teachers (lectures, tutors, mentors or industrial professionals, etc.) in groups both in and outside of class*, and item e, *individual private study (eg: searching literature, reading, writing reports, preparing presentations or exams, etc.)*; the other two items were related with team-based SDL, including item d, *studying/working in groups without supervision from teachers (lectures, tutors, mentors or industrial professionals, etc.) in groups both in and outside of class*, and item f, *other (eg: discussing with peers by email, informal chatting with peers or friends, etc.)*.

Accordingly, the SDL time in this experiment can be composed of these two categories, time for private SDL and time for team-based SDL.

Step 2 Categories of learner engagement

The items of learner engagement in the questionnaire were designed based on the learner engagement theory. According to the definition of learner engagement, there are three criteria in learner engagement: cognitive, behavioral, and affective (Pintrich and De Groot, 1990; Pintrich and Schrauben, 1992). To find out if the items designed in this questionnaire fall into any of the criteria, the method of factor analysis (SPSS 18.0) was used to identify the underlying properties of learner engagement in this research. The KMO and Bartlett’s test of the learner engagement showed that its value of KMO is greater than .70 (KMO = 0.768), so these items were fairly suitable for factor analysis (Wu, 2003, p67). Details were shown in Table 7.11:

| Kaiser-Meyer-Olkin Measures of Sampling Adequacy | .768 |
| Bartlett Test of Sphericity | Approx. Chi-Square | 709.545 |
| | Df | 36 |
| | Sig. | .000 |

Table 7.11. KMO and Bartlett’s test of the items of learner engagement.
Then, with the extraction method of Principal Component Analysis and Rotation method of Varimax with Kaiser Normalization, three factors of learner engagement were extracted, as shown in Table 7.12:

Table 7.12. Factor analysis of items of learner engagement.

<table>
<thead>
<tr>
<th>Items of learner engagement in the questionnaire</th>
<th>Cognitive</th>
<th>Behavioral</th>
<th>Affective</th>
</tr>
</thead>
<tbody>
<tr>
<td>g. I had confidence to do my share of work well on my own.</td>
<td>.750</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. I often reflected on the progress of my work.</td>
<td>.722</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. I was able to manage my time well in this project.</td>
<td>.656</td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. I like meeting challenges in my study.</td>
<td>.548</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. I took a leadership role in the teamwork.</td>
<td></td>
<td>.858</td>
<td></td>
</tr>
<tr>
<td>d. I took more responsibility for the project than my teammates.</td>
<td></td>
<td>.820</td>
<td></td>
</tr>
<tr>
<td>b. I was active in the team discussion.</td>
<td></td>
<td>.591</td>
<td></td>
</tr>
<tr>
<td>i. I prefer traditional teaching methods (e.g.: lectures + exams, etc.)</td>
<td></td>
<td></td>
<td>-.809</td>
</tr>
<tr>
<td>a. I like the way of team learning in the project.</td>
<td></td>
<td></td>
<td>.674</td>
</tr>
<tr>
<td>(%) Variance explained</td>
<td>23.605</td>
<td>21.627</td>
<td>17.492</td>
</tr>
</tbody>
</table>

It can be seen in Table 7.12, the items of learner engagement fell into three clusters, which can be taken as three categories of learner engagement. In the left column, the first 4 items, including g., f., e. and h, emphasized students mental efforts (e.g. cognitive and meta-cognitive strategies) in the learning tasks involved in PBL, so these 4 items fell into the category of cognitive, or psychological learner engagement; the 3 items in the middle, including c., d., and b., emphasized the actual performance in the learning activities students participated in, so these 3 items fell into the category of behavioral learner engagement; the last 2 items, including i. and a., emphasized students’ emotional reactions to the learning activities, so they fell into the category of affective learner engagement.
Thus, by using the method of factor analysis, the 9 items of the general learner engagement was classified into three specific categories, i.e. cognitive, behavioral, and affective, based on the theory of learner engagement.

Step 3 Categories of learning improvement

To find out if the 10 items of learning improvement reported by students in the questionnaire fall into different categories, again the method of factor analysis (SPSS 18.0) was applied to identify their underlying properties. The KMO and Bartlett’s test of the learning improvement showed that its value of KMO is greater than .80 (KMO = 0.884), so the items of learning improvement were suitable for factor analysis, as shown in Table 7.13:

Table 7.13. KMO and Bartlett’s test of the learning improvement.

| Kaiser-Meyer-Olkin Measures of Sampling Adequacy | .844 |
| Bartlett Test of Sphericity | Approx. Chi-Square | 979.989 |
| Df | 45 |
| Sig. | .000 |

Then, by using the extraction method of Principal Component Analysis and Quartimax Rotation method, two specific categories of student improvement were extracted, as shown in Table 7.14:
Table 7.14. Factor analysis of items of learning improvement.

<table>
<thead>
<tr>
<th>Items of learning improvement</th>
<th>Transferable skills</th>
<th>Design ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>h. The ability to deal with difficulties in your own share of work</td>
<td>.796</td>
<td></td>
</tr>
<tr>
<td>g. The ability to reflect on and monitor the project progress</td>
<td>.774</td>
<td></td>
</tr>
<tr>
<td>i. The ability to deal with difficulties in the teamwork (e.g. others work behind schedule; team conflicts, etc)</td>
<td>.753</td>
<td></td>
</tr>
<tr>
<td>e. Time management skills</td>
<td>.736</td>
<td></td>
</tr>
<tr>
<td>j. Oral and/or written communication ability.</td>
<td>.729</td>
<td></td>
</tr>
<tr>
<td>f. Independent learning ability</td>
<td>.672</td>
<td></td>
</tr>
<tr>
<td>d. The ability to work effectively in a team</td>
<td>.571</td>
<td></td>
</tr>
<tr>
<td>b. Evaluating design concepts/solutions ability</td>
<td>.880</td>
<td></td>
</tr>
<tr>
<td>a. Generating design concepts/solutions ability</td>
<td>.858</td>
<td></td>
</tr>
<tr>
<td>c. Knowledge application ability (eg: engineering science, mathematics, etc)</td>
<td>.668</td>
<td></td>
</tr>
<tr>
<td>(%) Variance explained</td>
<td>38.546</td>
<td>23.994</td>
</tr>
</tbody>
</table>

It can be seen in Table 7.14, the items of learning improvement fell into two clusters, which can be taken as two categories of learner engagement. In the left column, the former 7 items, including h, g, i, e, j, f, and d, emphasized the soft skills (e.g. time management, effective teamwork, communication ability, etc.) involved in PBL, so these 7 items was labeled as the category of transferable skills; the latter 3 items, including b, a, and c, emphasized the ability in engineering design activities (e.g. critical thinking ability, evaluation ability, knowledge application ability, etc.), so these 3 items was labeled as the category of design ability.

In this way, the 10 items of learning improvement designed in the questionnaire were classified into two specific categories, i.e., transferable skills and design ability.

With the categories of SDL time, learner engagement and learning improvement having been identified, further analysis of the relation between them was conducted in the same way as the

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analysis of the relation between general SDL time, learner engagement and general learning improvement.

7.4.2.4 Analyzing the Relation between Other Parameters and PBL Effectiveness

Other parameters refer to the design problem, lecture, tutorial and teamwork designed in the questionnaire.

The degrees of students’ perception on these four parameters were designed at a 5 points Likert type scale, from Strongly agree to Strongly disagree, the same as the degree of learner engagement. Thus, they can be quantified the same way as the quantification of learner engagement, i.e. 1= Strongly agree; 2= Agree; 3= Neither agree or disagree; 4= Disagree; 5= Strongly disagree. The smaller the value reported by an individual was, the higher degree the individual student perceived; the greater the value reported by an individual is, the lower degree the individual student perceived. The analysis of the relation between these four parameters and PBL effectiveness was also the same way as that of the relation between learner engagement and PBL effectiveness.

7.4.2.5 Analyzing the Influence of Previous Industrial Experience on the Model of PBL Effectiveness

The industrial experience designed in the questionnaire was at nominal scale, one is with previous industrial experience; the other is without. Accordingly, students were divided into two groups on the basis of these two categories. Then the relation between SDL, learner engagement and learning effectiveness were analyzed separately in these two groups of students. Finally, comparison was made to find the differences between the two groups of students.

7.5 FINDINGS

In this section, the moving average of 5 and 10 were chosen for SDL time and the moving average of 1 and 2 were chosen for learner engagement, team dynamics, design problem, tutorial and lecture (with DT representing the local interval and DS representing the moving forward length). Graphs of the trends between these parameters and PBL effectiveness based on the PBL Effectiveness in Engineering Design
the moving average were shown in figures for comparison, and the corresponding polynomial regression information was shown in tables for reference, including model of the moving average curve, $F$ value for the model, $P$ value, R-Square, Root-MSE (SD) and Number of central points.

The significance of the multiple regression models was tested with $F$ Value and its corresponding $P$ value. The goodness of fit was tested by R-Square. The value of R-Square ranges from 1 to zero; the closer R-Square is to 1, the better the fit is; the closer R-Square is to zero, the poorer the fit is (Dowdy, Wearden and Chilko, 2004, p453, p240).

### 7.5.1 The Relation between SDL Time and PBL Effectiveness

#### 7.5.1.1 The Relation between SDL time and Learning Improvement in Year1

The trends of the relation between SDL time and learning improvement in year 1 with moving average of 5 and 10 and the corresponding polynomial regression information were shown in Figure 7.4 and Table 7.15 below:

![Figure 7.4. The relation between SDL time and PBL effectiveness in year 1.](image)
Table 7.15. Polynomial Regression information for the relation between SDL time and learning improvement in year 1.

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model ( (Y = A + B1\times X + B2\times X^2) )</th>
<th>( F )-Value</th>
<th>( P )-Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>( N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA = 5</td>
<td>( 36.57418+1.16232X-0.01051X^2 )</td>
<td>19.0046</td>
<td>1.90892E-4</td>
<td>0.76004</td>
<td>3.42633</td>
<td>15</td>
</tr>
<tr>
<td>MA = 10 (1)</td>
<td>( 38.73083+1.01039X-0.00869X^2 )</td>
<td>60.00733</td>
<td>&lt;0.0001</td>
<td>0.89553</td>
<td>1.81668</td>
<td>17</td>
</tr>
<tr>
<td>MA = 10 (2)</td>
<td>( 37.44081+1.05552X-0.00912X^2 )</td>
<td>49.17114</td>
<td>1.9014E-4</td>
<td>0.9425</td>
<td>1.66498</td>
<td>9</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.4, it was obvious that the quadratic model was suitable to be chosen for describing the relation between SDL time and PBL effectiveness in year 1. From Figure 7.4, it can be seen that the three moving average curves resembled each other well and demonstrated the same trend.

From Table 7.15, it can be seen that all the three quadratic models were statistically significant \((P<0.0001)\). So these models were good predictors of PBL effectiveness. The R-Square values of the three models were greater than 0.7, indicating that more than 70% of the variability in PBL effectiveness can be explained by the three models.

The actual maximum points of the models can be found by setting the first derivative of \( Y \) with respect to \( X \) equal to zero (Dowdy, Wearden and Chilko, 2004, p490). Thus the maximum \( Y \)s of the three models were at

\[
Xm1 = -b1/2*b2 = -1.16232/2*(-0.01051) = 55
\]

\[
Xm2 = -b1/2*b2 = -1.01039/2*(-0.00869) = 58
\]

\[
Xm3 = -b1/2*b2 = -1.05552/2*(-0.00912) = 58
\]

The implication from the trends and maximum points in the three models is that in year 1 the optimal PBL effectiveness occurs at 55%-58% SDL time. When SDL time is spent greater than 55%-58%, there is not likely to be any further increase in the learning improvement in PBL. On the contrary, the learning improvement in PBL would begin to decrease with the spending of a
greater amount of SDL time.

7.5.1.2 The Relation between SDL Time and Learning Improvement in Year 2

The trends of the relation between SDL time and learning improvement in year 2 with moving average of 5 and 10 were shown in Figure 7.5:

![Figure 7.5. The relation between SDL time and PBL effectiveness in year 2.](image)

It can be seen from figure 7.5 that the trends of year 2 moving average curves were not obvious. Thus, comparisons between types of linear, quadratic, cubic and quartic curves were made and the information about how well the data of year 2 are fit by each type of curve was shown in Table 7.16:
Table 7.16. Polynomial Regression information for the relation between SDL time and learning improvement in year 2.

<table>
<thead>
<tr>
<th>Moving average of 5</th>
<th>Curve</th>
<th>Model</th>
<th>$F$ Test</th>
<th>$P$ Value</th>
<th>R-Square</th>
<th>MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>$Y = 66.65338 - 0.0702X$</td>
<td>1.85345</td>
<td>0.21049</td>
<td>0.1881</td>
<td>2.57957</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Quadratic</td>
<td>$Y = 90.37173 - 0.81526X + 0.00553X^2$</td>
<td>2.72191</td>
<td>0.13351</td>
<td>0.43747</td>
<td>2.29543</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cubic</td>
<td>$Y = 142.52949 - 3.31057X + 0.04376X^2 - 1.88651E-4X^3$</td>
<td>1.8663</td>
<td>0.23613</td>
<td>0.48271</td>
<td>2.37757</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartic</td>
<td>$Y = 662.43493 - 36.24492X + 0.80522X^2 - 0.00782X^3 + 2.80439E-5X^4$</td>
<td>2.23795</td>
<td>0.20022</td>
<td>0.64162</td>
<td>2.16783</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Moving average of 10</th>
<th>Curve</th>
<th>Model</th>
<th>$F$ Test</th>
<th>$P$ Value</th>
<th>R-Square</th>
<th>MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>$Y = 59.13735 + 0.02187X$</td>
<td>0.28108</td>
<td>0.60882</td>
<td>0.03029</td>
<td>2.16322</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Quadratic</td>
<td>$Y = 71.59939 - 0.35333X + 0.00268X^2$</td>
<td>0.54013</td>
<td>0.60251</td>
<td>0.11897</td>
<td>2.18701</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cubic</td>
<td>$Y = 123.96268 - 2.74691X + 0.03794X^2 - 1.67912E-4X^3$</td>
<td>0.51786</td>
<td>0.68317</td>
<td>0.18163</td>
<td>2.25334</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartic</td>
<td>$Y = 211.5653 + 12.83623X + 0.28586X^2 + 0.00277X^3 + 9.89042E-6X^4$</td>
<td>5.39958</td>
<td>0.0344</td>
<td>0.7826</td>
<td>1.25447</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From Table 7.16, it can readily be seen that the R-Square values of the quartic curves were greater than those of other three curves in both moving average of 5 and 10 (0.64162 and 0.7826 respectively), and its MSE values were the smallest for the four models (2.16783 and 1.25447 respectively). The $F$ test for the quartic model of moving average 10 was significant ($P<0.05$), the only significant $F$ test among the four models. The criteria which were used here for comparison all indicated that the quartic curve was superior fit to those for other types of curves, thus the quartic curve was chosen to represent the relation between SDL time and PBL effectiveness, as shown in Figure 7.5.

From Figure 7.5 it can be seen that the quartic models of moving average of 5 and 10 showed similar trends, each with one relative maximum point (point A in Figure 7.5), one minimum point (point B in Figure 7.5) and one relative minimum point (point C in Figure 7.5); the difference between the two curves was that the former curve was much flatter than the latter. Because the $F$ test for the quartic model of moving average of 5 was nonsignificant ($P>0.05$), so it was put here only for reference. The focus here was only on the quartic curve of moving
average of 10.

It can be found from the quartic curve of moving average of 10 in Figure 7.5 that the relative maximum Y (point A) was at about 70% SDL time, the minimum Y (point B) was at 55% SDL time, and the relative minimum Y (point C) was at about 90% SDL time. The implication from the trend and maximum and minimum points in the quartic model of moving average of 10 is that when SDL time was spent at 55% SDL time and 90% SDL time, the learning improvement in PBL would be likely to reach the lowest or relative lowest level; Any other amount of SDL time would bring an increase in the PBL improvement. The spending of 70% SDL time could bring a relative high learning improvement, whereas the amount of SDL time close to the two extremes, 0% and 100%, may bring even higher learning improvement.

7.5.1.3 The Relation between SDL Time and Learning Improvement in Year 3 & 4

The trends of the relation between SDL time and learning improvement in year 3 & 4 with moving average of 5 and 10 were shown in Figure 7.6 and the corresponding polynomial regression information was shown in Table 7.17:

![Figure 7.6. The relation between SDL time and PBL effectiveness in year 3&4.](image)
Table 7.17. Polynomial Regression information for the relation between SDL time and learning improvement in year 3&4.

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model (Y = A + B1<em>X + B2</em>X^2)</th>
<th>(F) Value</th>
<th>(P) Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =5</td>
<td>-116.86562+4.6899X-0.02965X^2</td>
<td>14.07129</td>
<td>0.00884</td>
<td>0.84914</td>
<td>1.84111</td>
<td>8</td>
</tr>
<tr>
<td>MA =10 (1)</td>
<td>-78.30525+3.74299X-0.02398X^2</td>
<td>8.43131</td>
<td>0.02501</td>
<td>0.7713</td>
<td>1.90345</td>
<td>8</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.6, it was obvious that the quadratic model was suitable to be chosen for describing the relation between SDL time and PBL effectiveness in year 3 & 4. From Figure 7.6, it can be seen that the two moving average curves resembled each other well and demonstrated similar trends.

From Table 7.17, it can be seen that both the two quadratic models were statistically significant \((P <0.05)\). So these two models were good predictors of PBL effectiveness. The R-Square values of the two models were greater than 0.7, indicating that more than 70% of the variability in PBL effectiveness can be explained by the two models.

Again the actual maximum points of the models can be found by setting the first derivative of y with respect to x equal to zero (Dowdy, Wearden and Chilko, 2004, p490). Thus the maximum Ys of the two models were at

\[Xm1 = \frac{-b1}{2*b2} = \frac{-4.6899}{2*(-0.02965)} = 79\]
\[Xm2 = \frac{-b1}{2*b2} = \frac{-3.74299}{2*(-0.02398)} = 78\]

The implication from the trends and maximum points in the two models is that in year 3 & 4, the optimal PBL effectiveness occurs at 78-79% SDL time. When SDL time is spent greater than 78-79%, there is not likely to be any further increase in the learning improvement in PBL. On the contrary, the learning improvement in PBL would begin to decrease with the spending of a greater amount of SDL time.
D. Comparison of the relation between SDL time and PBL effectiveness across academic years

With the relation between SDL time and PBL effectiveness being found out in each academic year, comparison was made between them. For the sake of consistency, curves of moving average of 10 (DT = 10, DS = 5) were chosen for comparison across academic years, as shown in Figure 7.7:

![Figure 7.7. Comparison of the relation between SDL time and PBL effectiveness across academic years.](image)

It can be seen from Figure 7.7 that the maximum Y values in year 1 and year 3 & 4 (point A & B) occur sequentially with the increase of the SDL time, one is at 58\% SDL time, the other is at 78\% SDL time, indicating that with the advance of academic years (with the exception of year 2), more SDL time is likely to be required for the optimal learning improvement to be achieved.

It can be noticed that the maximum Y value in year 1 (point A) and the minimum Y value of year 2 (point C) occur at the similar SDL time, one is 58\% and the other is about 55\%. This indicates that the optimal SDL time which brings the highest learning improvement in year 1 is likely to lead to just the opposite result in year 2 by bring the lowest learning improvement.

In addition, it can also be found that the amount of SDL time which brings the maximum Y value in year 3 & 4 (point B) is roughly between the amount of SDL time which brings the relative maximum Y value (point E) and the amount of SDL time which leads to the relative

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minimum Y value (point D) in year 2. This indicates that a little bit less amount of the optimal SDL time which brings the highest learning improvement in year 3 & 4 would be likely to bring the relative highest learning improvement in year 2, and a little bit greater amount of the optimal SDL time which brings the highest learning improvement in year 3 & 4 might lead to the relative lowest learning improvement in year 2.

7.5.2 The Relation between Learner Engagement and PBL Effectiveness

7.5.2.1 The Relation between Learner Engagement and PBL Effectiveness in Year 1

The trends of the relation between learner engagement and learning improvement in year 1 at moving average of 1 and 2 were shown in Figure 7.8:

![Figure 7.8](image)

Figure 7.8. The relation between learner engagement and PBL effectiveness in year 1.

From the mapping of the central point data shown in Figure 7.8, it can be seen that both the linear model and the quadratic model would be suitable for describing the relation between learner engagement and PBL effectiveness in year 1. To find out the best fit, comparisons were made between the types of linear and quadratic models, as shown in Table 7.18:
Table 7.18. Polynomial Regression information for the relation between learner engagement and learning improvement in year 1.

<table>
<thead>
<tr>
<th>Moving average</th>
<th>Curve</th>
<th>Model</th>
<th>$F$ Test for model</th>
<th>$P$ Value</th>
<th>R-Square</th>
<th>MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA=1</td>
<td>Linear</td>
<td>81.12235-1.04716X</td>
<td>43.37293</td>
<td>&lt;0.0001</td>
<td>0.79769</td>
<td>2.14507</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Quadratic</td>
<td>56.41664+2.33793X+0.1092X^2</td>
<td>41.77634</td>
<td>&lt;0.0001</td>
<td>0.89311</td>
<td>1.63533</td>
<td></td>
</tr>
<tr>
<td>MV=2</td>
<td>Linear</td>
<td>83.75753-1.26967X</td>
<td>32.51645</td>
<td>0.00126</td>
<td>0.84422</td>
<td>2.88598</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Quadratic</td>
<td>68.44204+0.72873X-0.05949X^2</td>
<td>49.47714</td>
<td>5.07363E-4</td>
<td>0.9519</td>
<td>1.75669</td>
<td></td>
</tr>
</tbody>
</table>

From Table 7.18, it can be seen that the $F$ tests for both the quartic model and the linear model were significant ($P<$0.0001). The R-Square values of the quartic curve (0.89311 and 0.9519 respectively) were greater than those of the linear curve (0.79769 and 0.84422 respectively) in both moving average of 1 and 2, and the MSE values of the quartic curves were also smaller. The criteria which were used here for comparison indicated that the quartic curve was superior fit to that of the linear curve, thus the quartic curve was chosen to represent the relation between learner engagement and PBL effectiveness in year 1, as shown in Figure 7.8.

From Figure 7.8, it can be seen that the two moving average curves mostly overlapped with each other, showing the similar trend: the Y value did not change when the X value was between 8 and 12; from 12 onward, the Y value gradually decreased with the increase in the X value. It should be noted that in the questionnaire design, the increase in the X value represented the decrease in learner engagement. Thus, the trends in Figure 7.8 indicates that in year 1, when the amount of learner engagement is great enough, the learning improvement is likely to remain steady; the lower amount of learner engagement would lead to decrease in learning improvement.

7.5.2.2 The Relation between Learner Engagement and PBL Effectiveness in Year 2

The trends of the relation between learner engagement and learning improvement in year 1 at moving average of 1 and 2 were shown in Figure 7.9:

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From the mapping of the central point data shown in Figure 7.9, it can be seen that, like in year 1, both the linear model and the quadratic model would be suitable for describing the relation between learner engagement and PBL effectiveness in year 2. To find out the best fit, comparisons were made between the types of linear and quadratic models, as shown in Table 7.19.

From Table 7.19, it can be seen that the $F$ test values for both the quadratic model and the linear model were significant ($P<0.01$). The R-Square values of the quadratic curve (0.86575 and 0.98718 respectively) were greater than those of the linear curve (0.78735 and 0.89034 respectively) in both moving average of 1 and 2, and the MSE values of the quadratic curves
were also smaller. The criteria which were used here for comparison indicated that the quadratic curve was superior fit to that of the linear curve, thus the quadratic curve was chosen to represent the relation between learner engagement and PBL effectiveness in year 2, as shown in Figure 7.9.

From Figure 7.9, it can be seen that the two moving average curves nearly overlapped with each other, showing the similar trend: the Y value did not change when the X value was between 8 and 10; from 10 onward, the Y value gradually decreased with the increase in the X value. Like in year 1, the trends in Figure 7.9 indicates that in year 2, when the amount of learner engagement is great enough, the learning improvement is likely to remain steady; the lower amount of learner engagement would lead to decrease in learning improvement.

**7.5.2.3 The Relation between Learner Engagement and PBL Effectiveness in Year 3&4**

The trends of the relation between learner engagement and learning improvement in year 3 & 4 at moving average 1 and 2 were shown in the Figure 7.10:

Figure 7.10. The relation between learner engagement and PBL effectiveness in year 3 & 4.
From the mapping of the central point data shown in Figure 7.10, it can be seen that, like in year 1 and year 2, both the linear model and the quadratic model would be suitable for describing the relation between learner engagement and PBL effectiveness in year 3 & 4. To find out the best fit, comparisons were made between the types of linear and quadratic models, as shown in Table 7.20.

From Table 7.20, it can be seen that the $F$ tests for both the quartic model and the linear model were significant ($P<0.01$). The R-Square values of the quartic curve (0.86391 and 0.95301 respectively) were greater than those of the linear curve (0.78018 and 0.91864 respectively) in both moving average of 1 and 2, and the MSE values of the quartic curves were also smaller than those of the linear curves. The criteria which were used here for comparison indicated that the quartic curve was superior fit to that of the linear curve, thus the quartic curve was chosen to represent the relation between learner engagement and PBL effectiveness in year 3 & 4, as shown in Figure 7.10.

From Figure 7.10, it can be seen that the two moving average curves overlapped in most parts and showed the similar trend. Different from the trends of year 1 and year 2, in year 3 & 4, from the very beginning the Y value decreased with the decrease of the x value. The trends in Figure 7.10 indicated that in year 3 & 4, learning improvement changes with the amount of learner engagement, and greater amount of learner engagement can bring higher learning improvement.
7.5.2.4 Comparison between Learner Engagement and PBL Effectiveness across Academic Years

With the relation between learner engagement and PBL effectiveness being found out in each academic year, comparison was made between them. For the sake of consistency, curves of moving average of 2 (DT = 2, DS = 2) were chosen for comparison across academic years, as shown in Figure 7.11:

![Graph showing comparison between learner engagement and PBL effectiveness across academic years.](image)

Figure 7.11. Comparison between learner engagement and PBL effectiveness across academic years.

It can be seen from Figure 7.11 that the curves across academic years demonstrated a similar trend in general, that is, the Y value decreases with the decrease of the x value. However, differences exist in the three curves. From in Figure 7.11, it can be seen that to achieve the same Y value, the X values of the three curves are different. The differences of the X value can be examined from the three extent of the Y value divided by the intersection points between the three curves, that is, point A and point B1/B2, as shown in Figure 7.12:
It can be seen that when the Y value is greater than about 68, at the same X value, the highest Y value is likely to be made by the curve of year 3 & 4; when the Y value is between 60 and 68, to achieve the same Y value, the X value of year 2 and year 3 & 4 is smaller than that of year 1; when the Y value is lower than 60, to achieve the same Y value, the X value of year 2 is smaller than that of year 1, which is further smaller than that of year 3 & 4.

The implication from the results is that more learning engagement can bring more learning improvement, and the highest learning improvement is likely to be achieved by the learner engagement in year 3 & 4; to achieve the same medium learning improvement, more learning engagement in year 2 and year 3 & 4 is needed than in year 1; when the same low learning improvement is made, the learning engagement of year 3 & 4 is smallest compared with the other two.

7.5.3 The Relation between the Two Parameters (SDL and LE) and PBL Effectiveness – A 3D Model

After the findings of the relation between SDL time and PBL effectiveness and the relation between learner engagement (LE) and PBL effectiveness was made respectively, the relation between these two parameters, i.e. SDL time and learner engagement, and PBL effectiveness
was analyzed by using Origin professional 6.0 and the findings were shown in 3D models.

7.5.3.1 The Relation between the Two Parameters (SDL and LE) and PBL Effectiveness in Year 1

The relation between the two parameters (SDL and LE) and PBL effectiveness in year 1 was shown in the 3D model in Figure 7.13:

![3D Model](image)

Figure 7.13. The relation between the two parameters (SDL and LE) and PBL effectiveness in year 1.

It can be seen from Figure 7.13 that for any value of learner engagement, there is a corresponding value of SDL time (about 55% - 60%) for the optimal learning improvement. Roughly speaking, the decrease of learner engagement value corresponds with the increase of learning improvement value except when learner engagement value is less than 16, where the learning improvement value remains steady (please note that the small learner engagement value represents greater learner engagement).

The findings indicate that for the students in PBL in year 1, no matter how much learner engagement they make, there exists a SDL time for the optimal learning improvement. Roughly speaking, students with high learner engagement could achieve better learning improvement than students with low learner engagement. However, when the learner engagement is great
enough (less than 16 as shown in Figure 7.13), the learning improvement becomes steady, which implies that for students who show great enough learner engagement, there might be some other factors influencing the learning improvement such as learning strategies.

7.5.3.2 The relation between the two parameters (SDL and LE) and PBL effectiveness in year 2
The relation between the two parameters (SDL and LE) and PBL effectiveness in year 2 was shown in the 3D model in Figure 7.14:

![3D model](image)

Figure 7.14. Relation between the two parameters (SDL and LE) and PBL effectiveness in year 2.

It can be seen from Figure 7.14 that for most values of learner engagement (from about 16.2 onwards), there is a corresponding value of SDL time for the optimal learning improvement. When the learner engagement value is less than 16.2, the increase of SDL time corresponds with the increase of the value of learning improvement; when the learner engagement is about 16.5, the greatest value of learning improvement could be achieved at SDL time of 70%; when the learner engagement value is low, it can be found that the changes of learning improvement with the SDL time are quite small.

The findings indicate that for the students in PBL in year 2, in most cases, no matter how much learner engagement is made, there is a SDL time for optimal learning improvement. When the
learner engagement is great enough (less than 16.2 as shown in Figure 7.14), the more SDL time is spent, the higher learning improvement is likely to be achieved; when learner engagement is low enough, the influence of the amount of SDL time on learning improvement would become small; when learner engagement is about 16.5 and SDL time is about 70%, the optimal learning improvement of the model could be achieved.

7.5.3.3 The relation between the two parameters (SDL and LE) and PBL effectiveness in year 3&4

The relation between the two parameters (SDL and LE) and PBL effectiveness in year 3 & 4 was shown in the 3D model in Figure 7.15:

![Figure 7.15. The relation between the two parameters (SDL and LE) and PBL effectiveness in year 3 & 4.](image)

It can be seen from Figure 7.15 that for any value of learner engagement, there is a corresponding SDL time (about 80%) for the optimal learning improvement value. The decrease of the learner engagement value corresponds with the increase of learning improvement value. The greatest learning improvement value occurs when learner engagement is about 17.

The findings indicate that for the students in PBL in year 3 & 4, no matter how much learner engagement is made, there exists a SDL time for the optimal learning improvement. Students
with high learner engagement could achieve better learning improvement than students with low learner engagement. When learner engagement is about 17 and SDL time is 80%, the optimal learning improvement of the model could be achieved.

7.5.3.4 Summary

It can be found from the findings in the above three 3D models that for any learner engagement value, there is a corresponding optimal SDL time. That is to say, in PBL, no matter how much learner engagement is involved, an appropriate amount of SDL time would be important for the learning improvement. This indicates that SDL time is an important parameter in PBL in engineering design.

7.5.4 The Relation between Categorized SDL time, Learner Engagement and PBL Effectiveness

7.5.4.1 The Relation between SDL Time and Categorized Learning Improvement

A. The relation between SDL time and design ability improvement

a. The relation between SDL time and design ability improvement in year 1

The trends of the relation between SDL time and design ability improvement in year 1 with moving average of 5 and 10 were shown in Figure 7.16 and the corresponding polynomial regression information was shown in Table 7.21 below:
From the mapping of the central point data shown in Figure 7.16, it can be seen that the quadratic model was suitable to be chosen for describing the relation between SDL time and design ability improvement in year 1. The three moving average curves demonstrated the similar trend, with the model of moving average 5 and model of moving average of 10 (2) overlapped to much extent.

From Table 7.21, it can be found that the $F$ test for the model of moving average of 5 was nonsignificant ($P>0.05$), and the R-Square was small (only 0.29954); by comparison, the $F$ tests for the two models of moving average of 10 were significant ($P<0.05$), and the R-Square values were much greater (0.71652 and 0.83517 respectively). So the two models of moving average of 10 were the good predictors of the relation between SDL time and design ability improvement.
The model of moving average of 5 was a poor predictor and was put here only for reference.

Then the maximum points of the three models were found. The maximum Ys of the three models were at

\[ X_{m1} = -\frac{b_1}{2}b_2 = -\frac{0.04407}{2}(-3.60398 \times 10^{-4}) = 61 \]
\[ X_{m2} = -\frac{b_1}{2}b_2 = -\frac{0.06556}{2}(-5.53714 \times 10^{-4}) = 59 \]
\[ X_{m3} = -\frac{b_1}{2}b_2 = -\frac{0.05155}{2}(-4.54987 \times 10^{-4}) = 57 \]

It can be seen that the three models shared similar maximum points in their trends. The implication from the results is that in year 1, the optimal design ability improvement occurs at 57-59% SDL time. When SDL time is spent greater than 57-59%, there is not likely to be any further increase in the design ability improvement in PBL. On the contrary, the design ability improvement would begin to decrease with the spending of a greater amount of SDL time.

b. SDL time and design ability improvement in year 2

The trends of the relation between SDL time and design ability improvement in year 2 with moving average of 5 and 10 were shown in Figure 7.17 and the corresponding polynomial regression information was shown in Table 7.22 below:
The Model of PBL Effectiveness in Engineering Design

Figure 7.17. Relation between SDL time and design ability improvement in year 2.

Table 7.22. Polynomial Regression information for the relation between SDL time and design ability improvement in year 2.

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model (Y = A + B_1X + B_2X^2 + B_3X^3)</th>
<th>(F) Value</th>
<th>(P) Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =5</td>
<td>-8.52988 + 0.78274X - 0.01291X^2 + 6.69485E-5X^3</td>
<td>7.74138</td>
<td>0.01741</td>
<td>0.79469</td>
<td>0.2172</td>
<td>10</td>
</tr>
<tr>
<td>MA =10</td>
<td>-7.94628 + 0.7311X - 0.0118X^2 + 6.00145E-5X^3</td>
<td>16.49953</td>
<td>0.00148</td>
<td>0.8761</td>
<td>0.14915</td>
<td>11</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.17, it was obvious that the cubic model was suitable to be chosen for describing the relation between SDL time and design ability improvement in year 2. From Figure 7.17, it can be seen that the two moving average curves resembled each other very well and overlapped to much extent.

From Table 7.22, it can be seen that both the two cubic models were statistically significant \((P<0.05)\). So these two models were good predictors of design ability improvement. The R-Square values of the two models were greater than 0.7, indicating that more than 70% of the variability in design ability improvement can be explained by the two models.
It can be found from the cubic curves of moving average of 5 and 10 in Figure 7.17 that the relative maximum Y (point A) was at about 50% SDL time, the relative minimum Y (point B) was at 80% SDL time. The implication from the trend in the two cubic models is that when SDL time was spent greater than 50% SDL time, there is not likely to be any further design ability improvement except when the amount of SDL time was near 100%. The result also indicated that the design ability improvement would begin to decrease with the spending of a greater amount of SDL time. When the spending of SDL time was 80%, the design ability improvement would be likely to reach a relative lowest level.

c. SDL time and design ability improvement in year 3 & 4

The trends of the relation between SDL time and design ability improvement in year 3 & 4 with moving average of 5 and 10 were shown in Figure 7.18 and the corresponding polynomial regression information was shown in Table 7.23 below:

Table 7.23. Polynomial Regression information for the relation between SDL time and design ability improvement in year 3 & 4.

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model</th>
<th>$F$ Value</th>
<th>$P$ Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =5</td>
<td>$-12.52478 + 0.48572X - 0.00305X^2$</td>
<td>17.3959</td>
<td>0.0056</td>
<td>0.87435</td>
<td>0.16769</td>
<td>8</td>
</tr>
<tr>
<td>MA =10</td>
<td>$-8.57046 + 0.38863X - 0.00246X^2$</td>
<td>16.62579</td>
<td>0.00618</td>
<td>0.86929</td>
<td>0.14346</td>
<td>8</td>
</tr>
</tbody>
</table>
From the mapping of the central point data shown in Figure 7.18, it was obvious that the quadratic model was suitable to be chosen for describing the relation between SDL time and design ability improvement in year 3 & 4. From Figure 7.18, it can be seen that the two moving average curves resembled each other very well.

From Table 7.23, it can be seen that both the two quadratic models were statistically significant \((P<0.01)\). So these two models were good predictors of design ability improvement. The R-Square values of the two models were greater than 0.8, indicating that more than 80% of the variability in design ability improvement can be explained by the two models.

Then the maximum points of the two models were found. The maximum Ys of the two models were at

\[
X_{m1} = -b_1/2*b_2 = -0.48572/2*(-0.00305) = 80 \\
X_{m2} = -b_1/2*b_2 = -0.38863/2*(-0.00246) = 79
\]

The implication from the trends and maximum points in the two models is that in year 3 & 4, the optimal design ability improvement occurs at 79-80% SDL time. When SDL time is spent greater than 79-80%, there is not likely to be any further increase in the design ability improvement. On the contrary, the design ability improvement in PBL would begin to decrease with the spending of a greater amount of SDL time.

d. Comparison of SDL time and design ability improvement across academic years

With the relation between SDL time and design ability improvement being found out in each academic year, comparison was made between them. For the sake of consistency, curves of moving average of 10 (DT = 10, DS = 5) were chosen for comparison across academic years, as shown in Figure 7.19:
It can be seen from Figure 7.19 that the maximum Y values in year 1 and year 3 & 4 (point A & B) occur sequentially with the increase of the SDL time: one is at 59% SDL time, the other is at 79% SDL time, indicating that with the advance of academic years (with the exception of year 2), more SDL time is likely to be required for the optimal design ability improvement to be achieved.

The inconsistency occurs in year 2, in which the relative maximum Y value (point C) occurs at about 50% SDL time, the smallest amount of SDL time among the three models; in addition, the 80% SDL time which may bring the maximum Y value in year 3 & 4 (point B) is likely to lead to the relative minimum Y value in year 2 (point D). These indicate that the attainment of the relative optimal design ability improvement in year 2 requires less SDL time than in year 1 and year 3 & 4. In addition, the optimal SDL time of year 3 & 4 would be likely to bring just the opposite result in year 2.

Concerning the amount of the Y value, it can be seen that the maximum Y value in year 1(point A) is the greatest among the three models, with that of year 3 & 4 ranking the second (point B) and the relative maximum Y value of year 2 ranking the smallest (point C). This indicates that the biggest optimal design ability improvement is likely to occur in year 1, while the smallest
relative optimal design ability improvement might occur in year 2.

B. The relation between SDL time and transferable skill improvement

a. SDL time and transferable skill improvement in year 1

The trends of the relation between SDL time and transferable skill improvement in year 1 with moving average of 5 and 10 were shown in Figure 7.20 and the corresponding polynomial regression information was shown in Table 7.24 below:

From the mapping of the central point data shown in Figure 7.20, it was obvious that the quadratic model was suitable to be chosen for describing the relation between SDL time and transferable skill improvement in year 1. From Figure 7.20, it can be seen that the three moving average curves resembled each other well, with the two curves of moving average of 10

Table 7.24. Polynomial Regression information for the relation between SDL time and transferable skill improvement in year 1.

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model ( Y = A + B1*X + B2*X^2 )</th>
<th>( F ) Value</th>
<th>( P ) Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =5</td>
<td>3.03617+0.13763X-0.00124X^2</td>
<td>16.40729</td>
<td>3.68614E-4</td>
<td>0.73223</td>
<td>0.43406</td>
<td>15</td>
</tr>
<tr>
<td>MA =10 (1)</td>
<td>3.16754+0.12328X-0.00105X^2</td>
<td>48.31345</td>
<td>&lt;0.0001</td>
<td>0.87345</td>
<td>0.24804</td>
<td>17</td>
</tr>
<tr>
<td>MA =10 (2)</td>
<td>3.08091+0.12759X-0.0011X^2</td>
<td>35.44987</td>
<td>4.74984E-4</td>
<td>0.92198</td>
<td>0.23701</td>
<td>9</td>
</tr>
</tbody>
</table>

Figure 7.20. Relation between SDL time and transferable skill improvement in year 1.
overlapping to much extent.

From Table 7.24, it can be seen that all the three quadratic models were statistically significant ($P<0.0001$). So these three models were good predictors of transferable skill improvement. The R-Square values of the three models were greater than 0.7, indicating that more than 70% of the variability in transferable skill improvement can be explained by the three models.

Then the actual maximum points of the models were found. The maximum Ys of the three models were at

\[ X_{m1} = -\frac{b_1}{2b_2} = -\frac{-0.13763}{2*(-0.00124)} = 55 \]
\[ X_{m2} = -\frac{b_1}{2b_2} = -\frac{-0.12328}{2*(-0.00105)} = 59 \]
\[ X_{m3} = -\frac{b_1}{2b_2} = -\frac{-0.12759}{2*(-0.0011)} = 58 \]

The implication from the trends and maximum points in the three models is that in year 1, the optimal transferable skill improvement occurs at 55-59% SDL time. When SDL time is spent greater than 55-59%, there is not likely to be any further increase in the transferable skill improvement in PBL. On the contrary, the transferable skill improvement would begin to decrease with the spending of a greater amount of SDL time.

b. SDL time and transferable skill improvement in year 2

The trends of the relation between SDL time and transferable skill improvement in year 2 with moving average of 5 and 10 were shown in Figure 7.21 and the corresponding polynomial regression information was shown in Table 7.25 below:
The Model of PBL Effectiveness in Engineering Design

From the mapping of the central point data shown in Figure 7.21, it can be estimated that the quadratic model was suitable to be chosen for describing the relation between SDL time and transferable skill improvement in year 2. From Figure 7.21, it can be seen that the two moving average curves resembled each other to a certain extent, with the relative maximum Y value and the minimum and relative minimum Y value at roughly similar amount of SDL time respectively.

From Table 7.25, it can be found that the $F$ test for the quartic model of moving average of 5 was nonsignificant ($P>0.05$) and the R-Square was not great enough (R-Square = 0.67845). The

Table 7.25. Polynomial Regression information for the relation between SDL time and transferable skill improvement in year 2.

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model</th>
<th>$F$ Value</th>
<th>$P$ Value</th>
<th>R-Square</th>
<th>Root-MSE</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =5</td>
<td>$Y = A + B1<em>X + B2</em>X^2 + B3<em>X^3 + B4</em>X^4$</td>
<td>2.63738</td>
<td>0.15808</td>
<td>0.67845</td>
<td>0.23963</td>
<td>10</td>
</tr>
<tr>
<td>MA =10</td>
<td>$Y = A + B1<em>X + B2</em>X^2 + B3<em>X^3 + B4</em>X^4$</td>
<td>13.15246</td>
<td>0.00396</td>
<td>0.89763</td>
<td>0.13567</td>
<td>11</td>
</tr>
</tbody>
</table>

Figure 7.21. Relation between SDL time and transferable skill improvement in year 2.
$F$ test for the quartic model of moving average of 10 was significant ($P<0.01$), and the R-Square was great (R-Square = 0.89763). Thus, the model of moving average of 5 showed the possible good fitting of the trend and the model of moving average of 10 showed the statistically good fitting of the trend.

From Figure 7.21 it can be found that the relative maximum Y (point A) was at about 75% SDL time, the minimum Y (point B) was near 55% SDL time, and the relative minimum Y (point C) was at about 90% SDL time. The implication from the results was that when SDL time was at 55% and 90%, the transferable skill improvement in PBL would be likely to reach the lowest or the relative lowest level; any other amount of SDL time would bring an increase in the improvement. The spending of 75% SDL time could bring a relative high transferable skill improvement, whereas the amount of SDL time close to the two extremes, 45% backwards and 100%, may bring even higher learning improvement.

c. SDL time and transferable skill improvement in year 3 & 4
The trends of the relation between SDL time and transferable skill improvement in year 3 & 4 with moving average of 5 and 10 were shown in Figure 7.22 and the corresponding polynomial regression information was shown in Table 7.26:

![Figure 7.22. Relation between SDL time and transferable skill improvement in year 3 & 4.](image-url)
Table 7.26. Polynomial Regression information for the relation between SDL time and transferable skill improvement in year 3 & 4.

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model ( Y = A + B_1X + B_2X^2 )</th>
<th>( F ) Value</th>
<th>( P ) Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA = 5</td>
<td>(-10.80132+0.44798X-0.00284X^2)</td>
<td>10.38762</td>
<td>0.01657</td>
<td>0.80602</td>
<td>0.20775</td>
<td>8</td>
</tr>
<tr>
<td>MA = 10</td>
<td>(-6.83484+0.34993X-0.00225X^2)</td>
<td>6.13538</td>
<td>0.0451</td>
<td>0.71049</td>
<td>0.20847</td>
<td>8</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.22, it was obvious that the quadratic model was suitable to be chosen for describing the relation between SDL time and transferable skill improvement in year 3 & 4. From Figure 7.22, it can be seen that the two moving average curves resembled each other well.

From Table 7.26, it can be seen that both the two quadratic models were statistically significant \((P<0.05)\). So the two models were fairly good predictors of transferable skill improvement. The R-Square values of the two models were greater than 0.7, indicating that more than 70% of the variability in transferable skill improvement can be explained by the two models.

Then the actual maximum points of the models were found. The maximum Ys of the three models were at

\[ X_{m1} = \frac{-b_1}{2b_2} = -\frac{-0.44798}{2*(-0.00284)} = 79 \]
\[ X_{m2} = \frac{-b_1}{2b_2} = -\frac{-0.34993}{2*(-0.00225)} = 78 \]

The implication from the trends and maximum points in the two models is that in year 3 & 4, the optimal transferable skill improvement occurs at 78-79% SDL time. When SDL time is spent greater than 78-79%, there is not likely to be any further increase in the transferable skill improvement in PBL. On the contrary, the transferable skill improvement would begin to decrease with the spending of a greater amount of SDL time.
d. Comparison of the relation between SDL time and transferable skills improvement across academic years

With the relation between SDL time and transferable skill improvement being found out in each academic year, comparison was made between them. For the sake of consistency, curves of moving average of 10 (DT = 10, DS = 5) were chosen for comparison across academic years, as shown in Figure 7.23:

![Comparison of the relation between SDL time and transferable skill improvement across academic years.](image)

It can be seen from Figure 7.23 that the maximum Y values in year 1 and year 3 & 4 (point A & B) occur sequentially with the increase of the SDL time, one is at 59% SDL time, the other is at 78% SDL time, indicating that with the advance of academic years (with the exception of year 2), more SDL time is likely to be required for the optimal transferable skill improvement to be achieved.

It can be noticed that the maximum Y value in year 1 (point A) and the minimum Y value of year 2 (point C) occur at the similar SDL time, the former being 59% and the latter being 55%. This indicates that the optimal SDL time which brings the highest transferable skill improvement in year 1 would lead to just the opposite result in year 2 by bring the lowest transferable skill improvement.
On the other hand, the maximum Y value in year 3 & 4 (point B) and the relative maximum Y value of year 2 (point D) occur at the similar SDL time, one is 78% and the other is 75%. This indicates that the optimal SDL time which is likely to bring the highest transferable skill improvement in year 3 & 4 would also be likely to bring the relative highest transferable skill improvement in year 2.

e. Comparison between design ability improvement and transferable skill improvement across academic years

After the comparison of the relation between SDL time and design ability improvement and the relation between SDL time and transferable skill improvement was made respectively across academic years, the comparisons between design ability improvement and transferable skill improvement in each academic year were conducted, as shown in Figure 7.21- Figure 7.23. For the sake of consistency, curves of moving average of 10 (DT = 10, DS = 5) were chosen.
From Figure 7.24 and Figure 7.25, it can be seen clearly that in year 1 and year 3 & 4, the attainment of the optimal design ability improvement and transferable improvement occur at similar SDL time, about 59% in year 1 and 78-79% in year 3 & 4. In year 1, the attainment of design ability improvement is slightly higher that that of transferable skill improvement when the same amount of SDL time is spent. In year 3 & 4, it can be seen that the curves of design ability improvement and transferable skill improvement almost overlapped with each other,
indicating that the same amount of design ability improvement and transferable skill improvement is likely to be made when the same amount of SDL time is spent.

The case of year 2 is much more complicated. It can be seen that the trend of design ability improvement curve is conflicting with that of the transferable skill improvement curve in that relative maximum of design ability improvement (point a in Figure 7.26) and the minimum of transferable skill improvement (point b in Figure 7.26) occur at similar SDL time, 50-55%; likewise, the relative maximum of transferable skill improvement (point c in Figure 7.26) and the relative minimum of design ability improvement (point d in Figure 7.26) occur at similar SDL time, 75%-80%.

In year 2, the same amount of design ability improvement and transferable skill improvement can be achieved at the three intersection points A, B C, as shown in Figure 7.26, with the Y value of point A greater than that of point B which is further greater than that of point C. Thus, to achieve the optimal improvement for both design ability and transferable skills, the SDL time at point A, about 45%, is one choice. The other choice is towards 100% SDL time where the two curves of design ability improvement and transferable skill improvement almost overlapped, which indicates that the same amount of improvement can be achieved.

7.5.4.2 The Relation between Categorized SDL Time and General Learning Improvement

A. The relation between individual SDL time and general improvement

a. Individual SDL time and learning improvement in year 1

The trends of the relation between individual SDL time with moving average of 5 and 10 in year 1 were shown in Figure 7.27 and the corresponding polynomial regression information was shown in Table 7.27 below:
Table 7.27. Polynomial Regression information for the relation between individual SDL time and learning improvement in year 1.

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model ((Y = A + B1<em>X + B2</em>X^2))</th>
<th>(F) Value</th>
<th>(P) Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA = 5</td>
<td>57.06327 + 0.74909X - 0.01554X^2</td>
<td>8.84351</td>
<td>0.00941</td>
<td>0.68856</td>
<td>3.01065</td>
<td>11</td>
</tr>
<tr>
<td>MA = 10 (1)</td>
<td>61.3524 + 0.38872X - 0.00924X^2</td>
<td>12.33136</td>
<td>0.0036</td>
<td>0.75507</td>
<td>2.21789</td>
<td>11</td>
</tr>
<tr>
<td>MA = 10 (2)</td>
<td>61.26244 + 0.35335X - 0.00838X^2</td>
<td>4.47314</td>
<td>0.12584</td>
<td>0.74888</td>
<td>2.70434</td>
<td>6</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.27, it was obvious that the quadratic model was suitable to be chosen for describing the relation between individual SDL time and PBL effectiveness in year 1. From Figure 7.27, it can be seen that the three moving average curves roughly resembled each other well, with the curves of moving average of 10 overlapping to great extent.

From Table 7.27, it can be seen that the quadratic models of moving average of 5 and 10 (1) were statistically significant \((P<0.01)\). So these two models were good predictors of PBL effectiveness. The R-Square values of the two models were greater than 0.6, indicating that more than 60% of the variability in PBL effectiveness can be explained by the two models. The
R-Square value of the model of moving average of 10 (2) is also good (R-Square = 0.74888), yet $F$ test is nonsignificant ($P>0.05$). Thus, the model of moving average of 10 (2) showed the possible good fitting of the trend and the model of moving average of 5 and 10 (1) showed the statistically good fitting of the trend.

Then the actual maximum points of the models were found. The maximum Ys of the three models were at

\[
X_{m1} = \frac{-b_1}{2b_2} = \frac{-0.74909}{2(-0.01554)} = 24
\]

\[
X_{m2} = \frac{-b_1}{2b_2} = \frac{-0.38872}{2(-0.00924)} = 21
\]

The implication from the trends and maximum points in the two models is that in year 1 the optimal learning improvement occurs at 21-24% individual SDL time. When individual SDL time is spent greater than 21-24%, there is not likely to be any further increase in the learning improvement in PBL. On the contrary, the learning improvement would begin to decrease with the spending of a greater amount of individual SDL time.

b. Individual SDL time and general improvement in year 2

The trends of the relation between individual SDL time with moving average of 5 and 10 in year 2 were shown in Figure 7.28 and the corresponding polynomial regression information was shown in Table 7.28 below:
From the mapping of the central point data shown in Figure 7.28, it was obvious that the quadratic model was suitable to be chosen for describing the relation between individual SDL time and PBL effectiveness in year 2. From Figure 7.28, it can be seen that the two moving average curves roughly resembled each other well.

From Table 7.28, it can be seen that the $F$ test for the model of moving average of 5 was nonsignificant ($P>0.05$), and its R-Square is not good, only 0.47168. By comparison, the $F$ test for the model of moving average of 10 was statistically significant ($P<0.01$), so it was a good predictor of PBL effectiveness. The R-Square value of the model was fairly good, which was 0.67062. Thus, the model of moving average of 5 showed the possible good fitting of the trend and the model of moving average of 10 showed the statistically good fitting of the trend.
Then the actual maximum points of the models were found. The maximum Ys of the model of moving average of 10 was at

\[ X_{m2} = \frac{-b_1}{2b_2} = \frac{-0.66754}{2(-0.01051)} = 32 \]

The implication from the result is that in year 2 the optimal learning improvement occurs at 32% individual SDL time. When individual SDL time is spent greater than 32%, there is not likely to be any further increase in the learning improvement in PBL. On the contrary, the learning improvement would begin to decrease with the spending of a greater amount of individual SDL time.

c. Individual SDL time and general learning improvement in year 3 & 4

The trends of the relation between individual SDL time with moving average of 5 and 10 in year 3 & 4 were shown in Figure 7.29 and the corresponding polynomial regression information was shown in Table 7.29:
Table 7.29. Polynomial Regression information for the relation between individual SDL time and learning improvement in year 3&4.

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model ((Y = A + B1<em>X + B2</em>X^2))</th>
<th>(F) Value</th>
<th>(P) Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA = 5</td>
<td>61.53811+0.31651X-0.00497X^2</td>
<td>5.12412</td>
<td>0.02938</td>
<td>0.50613</td>
<td>2.82607</td>
<td>13</td>
</tr>
<tr>
<td>MA = 10</td>
<td>64.68375+0.16087X-0.00338X^2</td>
<td>19.30612</td>
<td>1.28156E-4</td>
<td>0.74812</td>
<td>2.13349</td>
<td>16</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.29, it was obvious that the quadratic model was suitable to be chosen for describing the relation between individual SDL time and PBL effectiveness in year 2. From Figure 7.29, it can be seen that the two moving average curves resembled each other well.

From Table 7.29, it can be seen that the \(F\) test for the two models were statistically significant \((P<0.05)\), so they are good predictors of PBL effectiveness. The R-Square value of the model of moving average of 5 was not very good, which was smaller than .60; by comparison, the R-Square value of the model of moving average of 10 was fairly good, which was greater than .70.

Then the actual maximum points of the models were found. The maximum Ys of the two models were at

\[
X_{m1} = -b1/2*b2 = -0.31651/2*(-0.00497) = 32
\]

\[
X_{m2} = -b1/2*b2 = -0.16087/2*(-0.00338) = 24
\]

The implication from the result is that in year 3 & 4 the optimal learning improvement occurs at 24-32% individual SDL time. When individual SDL time is spent greater than 24-32%, there is not likely to be any further increase in the learning improvement in PBL. On the contrary, the learning improvement would begin to decrease with the spending of a greater amount of individual SDL time.
d. Comparison of the individual SDL time and PBL effectiveness across academic years

With the relation between individual SDL time and learning improvement being found out in each academic year, comparison was made between them. For the sake of consistency, curves of moving average of 10 (DT = 10, DS = 5) were chosen for comparison across academic years, as shown in Figure 7.30:

![Figure 7.30. Comparison of the relation between individual SDL time and learning improvement across academic years.](image)

It can be seen from Figure 7.30 that the maximum Y values in year 1 and year 3 & 4 (point A & B) occurred at roughly similar SDL time, with 21% in the former and 24% in the latter. By comparison, the maximum Y value in year 2 (point C) was at the greatest amount of individual SDL time among the three curves, i.e. 32% SDL time.

In addition, it can be seen that at the same amount of the X value, the Y values are different across academic years. The differences can be examined from the two stages of the X value, divided by the intersection point between year 1 and year 2 curves (point D as shown in Figure 7.30), the X value of which is at about 34%. It can be seen that in stage 1, that is, from the 0% to 34%, the same amount of the X value can bring the highest Y value in year 3 & 4 curve, the second highest Y value in year 1 and the lowest in year 2; in stage 2, that is, from 34% onwards, the same amount of the X value can bring the highest Y value in year 3 & 4 again, yet second highest in year 2 and lowest in year 1.
The implication from the results is that to achieve the optimal learning improvement, more individual SDL time is needed in year 2 than that in year 1 and year 3 & 4; in addition, when the individual SDL time is less than 34%, the same amount the individual SDL time is likely to bring the highest learning improvement in year 3 & 4, and the lowest in year 2; when the individual SDL time is greater than 34%, the same amount the individual SDL time is likely to bring the highest learning improvement in year 3 & 4 again, yet the lowest in year 1.

B. The relation between team SDL time and general improvement

a. Team-based SDL time and general improvement in year 1

The trends of the relation between team-based SDL time with moving average of 5 and 10 in year 1 were shown in Figure 7.31 and the corresponding polynomial regression information was shown in Table 7.30 below:

![Figure 7.31. Relation between team SDL time and learning improvement in year 1.](image)

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model</th>
<th>F Value</th>
<th>P Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =5</td>
<td>$Y = A + B1X + B2X^2$</td>
<td>22.8591</td>
<td>&lt;0.0001</td>
<td>0.7786</td>
<td>1.74948</td>
<td>16</td>
</tr>
<tr>
<td>MA =10 (1)</td>
<td>$Y = A + B1X + B2X^2$</td>
<td>19.29967</td>
<td>1.28364E-4</td>
<td>0.74806</td>
<td>1.71144</td>
<td>16</td>
</tr>
<tr>
<td>MA =10 (2)</td>
<td>$Y = A + B1X + B2X^2$</td>
<td>35.09886</td>
<td>0.00114</td>
<td>0.93351</td>
<td>1.16588</td>
<td>8</td>
</tr>
</tbody>
</table>
From the mapping of the central point data shown in Figure 7.31, it was obvious that the quadratic model was suitable to be chosen for describing the relation between team SDL time and PBL effectiveness in year 1. From Figure 7.31, it can be seen that the three moving average curves resembled each other well.

From Table 7.30, it can be seen that all the three quadratic models were statistically significant ($P<0.01$). So these three models were good predictors of PBL effectiveness. The R-Square values of the three models were greater than 0.7, indicating that more than 70% of the variability in PBL effectiveness can be explained by the three models.

Then the maximum points of the curves were found. The maximum Ys of the three models were at

\[
X_{m1} = -\frac{b1}{2b2} = -\frac{0.51611}{2\times(-0.00615)} = 42
\]
\[
X_{m2} = -\frac{b1}{2b2} = -\frac{0.49167}{2\times(0.00552)} = 45
\]
\[
X_{m3} = -\frac{b1}{2b2} = -\frac{0.59133}{2\times(0.00639)} = 46
\]

The implication from the trends and maximum points in the three models is that in year 1, the optimal PBL effectiveness occurs at 42-46% team SDL time. When team SDL time is spent greater than 42-46%, there is not likely to be any further increase in the learning improvement in PBL. On the contrary, the learning improvement in PBL would begin to decrease with the spending of a greater amount of SDL time.

b. Team-based SDL time and general learning improvement in year 2

The trends of the relation between team-based SDL time with moving average of 5 and 10 were shown in Figure 7.32 and the corresponding polynomial regression information was shown in Table 7.31 below:
From Figure 7.32 it can be seen that the mapping of the central point data showed a kind of wavy pattern. After comparison, the fifth order model was chosen to describe the relation between SDL time and PBL effectiveness in year 2. From Figure 7.32, it can be seen that the two moving average curves resembled each other well.

From Table 7.31, it can be seen that the model of moving average of 5 was statistically nonsignificant \((P<0.05)\), although its R-Square is fairly good. By comparison, the model of moving average of 10 was greatly significant \((P<0.0001)\), indicating that it is a very good predictor of PBL effectiveness. In addition, the R-Square value of the model of moving average of 10 is 0.9282, which is very high.

From Table 7.31, it can be seen that the model of moving average of 5 was statistically nonsignificant \((P<0.05)\), although its R-Square is fairly good. By comparison, the model of moving average of 10 was greatly significant \((P<0.0001)\), indicating that it is a very good predictor of PBL effectiveness. In addition, the R-Square value of the model of moving average of 10 is 0.9282, which is very high.

\[ Y = A + B_1X + B_2X^2 + B_3X^3 + B_4X^4 + B_5X^5 \]

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model</th>
<th>(F) Value</th>
<th>(P) Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =5</td>
<td>(290.29678-35.11411X+1.94168X^2-0.04922X^3+5.80482E-4X^4-2.58049E-6X^5)</td>
<td>3.78996</td>
<td>0.06781</td>
<td>0.75952</td>
<td>2.55353</td>
<td>12</td>
</tr>
<tr>
<td>MA =10</td>
<td>(185.58315-20.2591X+1.15687X^2-0.02984X^3+3.55694E-4X^4-1.59248E-6X^5)</td>
<td>18.09822</td>
<td>7.06254E-4</td>
<td>0.9282</td>
<td>0.90708</td>
<td>13</td>
</tr>
</tbody>
</table>
of 10 was great, and the MSE is much small. Thus, the model of moving average of 5 showed the possible good fitting of the trend and the model of moving average of 10 showed the statistically good fitting of the trend.

It can be found from Figure 7.32 that there are two relative maximum points in the curves, point B and D, occurring at 35% and 70% SDL time respectively, and two relative minimum points, point A and C, occurring at 20% and 55% SDL time. It can be noticed that the four points A, B, C, and D represent the alternative occurrence of the relative maximum and minimum Y values in the curves, and the alternative interval is about 15%-20% SDL time, as shown in Figure 7.33:

![Figure 7.33. Time intervals in the relation between team SDL time and learning improvement in year 2.](image)

The implication from these is that in year 2, the learning improvement could be greatly influenced by the changes of team SDL time. The change interval of team SDL time is about 15%-20% team SDL time, which is likely to bring the alternation of the relative optimal learning improvement and the relative lowest learning improvement.

c. Team-based SDL time and general learning improvement in year 3 & 4

The trends of the relation between team-based SDL time with moving average of 5 and 10 in year 3 & 4 were shown in Figure 7.34 and the corresponding polynomial regression information was shown in Table 7.32:
From the mapping of the central point data in Figure 7.34 the trends of the two moving average curves were not obvious. After comparison, the quartic model was chosen to describe the relation between team SDL time and PBL effectiveness in year 3 & 4. The two curves roughly resembled each other, with the curve of moving average of 10 flatter than the curve of moving average of 5.

From Table 7.32, it can be seen that the model of moving average of 5 was statistically nonsignificant ($P<0.05$), and its R-Square is not very great ($R^2 = 0.61548$). By
comparison, the model of moving average of 10 was statistically significant ($P<0.01$), indicating that it is a good predictor of PBL effectiveness. In addition, the R-Square value of the model of moving average of 10 was fairly great ($R^2 = 0.72035$). Thus, the model of moving average of 5 showed the possible good fitting of the trend and the model of moving average of 10 showed the statistically good fitting of the trend.

It can be found from the curve of moving average of 10 that there is an obvious maximum $Y$ value at point C, occurring at team SDL time of 70%, as shown in Figure 7.35. This indicates that when team SDL time is spent greater than 70%, there is not likely to be any further increase in the learning improvement in PBL. On the contrary, the learning improvement in PBL would begin to decrease with the spending of a greater amount of team SDL time.

It can also be found from Figure 7.35 that within the increasing period of the $Y$ value, that is, from 0% to 70% team SDL time, there is a standstill period of the $Y$ value occurring from point A to point B, i.e. from 20% to 40% team SDL time. This indicates that during this team SDL time period, greater amount of team SDL time would not bring the increase in learning improvement.
d. Comparison of the team-based SDL time and PBL effectiveness across academic years

With the relation between team SDL time and learning improvement being found out in each academic year, comparison was made between them. For the sake of consistency, curves of moving average of 10 (DT = 10, DS = 5) were chosen for comparison across academic years, as shown in Figure 7.36:

![Figure 7.36. Comparison of the relation between team SDL time and learning improvement across academic years.](image)

It can be seen that the maximum Y values in year 1 and year 3 & 4 (point A and point B) occur sequentially with the increase of the team SDL time, from 45% SDL time in year 1 to 70% SDL time in year 3 & 4. This indicates that with the advance of academic years (with the exception of year 2), more team SDL time is likely to be required for the optimal PBL effectiveness to be achieved.

In the case of year 2, it can be found that the team SDL time for achieving the maximum Y value of year 1 (point A) is between the team SDL time for achieving the relative maximum Y value (point C) and relative minimum Y value of year 2 (point E); the team SDL time for achieving the maximum Y value of year 3 & 4 (point B) is of the same amount of the team SDL time for achieving the second relative maximum Y value (point D) of year 2. This indicates that when the optimal team SDL time of year 1 is applied to year 2, the relative optimal learning improvement can be achieved at a slightly less time whereas the relative lowest improvement is
likely to be caused at a slightly greater time. When the optimal team SDL time of year 3 & 4 applied to year 2, relative optimal learning improvement would be achieved.

7.5.4.3 The Relation between Categorized Learner Engagement and General Learning Improvement

As shown previously in section 7.4.2.3, the learner engagement in this experiment was divided into three categories: behavioral, cognitive and affective learning engagement. The following findings of learner engagement were based on these three categories.

A. The relation between the three categorized learner engagement and PBL effectiveness in year 1

The trends of the relation between the three categorized learner engagement and learning improvement in year 1 with moving average of 1 were shown in Figure 7.37 and the corresponding polynomial regression information was shown in Table 7.33 below:

![Figure 7.37. Relation between categorized learner engagement and learning improvement in year 1.](image-url)
Table 7.33. Polynomial Regression information for the relation between categorized learner engagement and learning improvement in year 1.

<table>
<thead>
<tr>
<th>Learner engagement</th>
<th>Model ( Y = A + B1<em>X + B2</em>X^2 )</th>
<th>( F ) Value</th>
<th>( P ) Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behavioral</td>
<td>66.19348+1.65645X-0.33448X^2</td>
<td>58.54124</td>
<td>&lt;0.0001</td>
<td>0.94359</td>
<td>2.6378</td>
<td>10</td>
</tr>
<tr>
<td>Cognitive</td>
<td>62.34052+2.76145X-0.27354X^2</td>
<td>115.21876</td>
<td>&lt;0.0001</td>
<td>0.96241</td>
<td>1.82606</td>
<td>12</td>
</tr>
<tr>
<td>Affective</td>
<td>67.45558+0.44967X-0.25495X^2</td>
<td>20.5541</td>
<td>0.00387</td>
<td>0.89156</td>
<td>2.18417</td>
<td>8</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.37, it can be found that the quadratic model was suitable to be chosen for describing the relation between the three categorized learner engagement and learning improvement in year 1.

From Table 7.33, it can be seen that all the three quadratic models were statistically significant \( (P<0.01) \). So these three models were good predictors of PBL effectiveness. The R-Square values of the three models were good, greater than 0.80, indicating that more than 80% of the variability in PBL effectiveness can be explained by the three models.

From Figure 7.37, it can be seen that, the curves of the three models generally demonstrated similar trends, with the Y value increasing with the decrease of the X value. However, it can be found that differences exist among the three curves. The differences were examined from the two extent of the Y value which was divided by the intersection points (point A) between affective and cognitive curves, as shown in Figure 7.37.

It can be seen that when the Y value is greater than 67, the greatest Y value (point B) is likely to be achieved by the cognitive curve other than the other two. When the Y value is below 67, to achieve the same Y value, the X value of the affective curve is the smallest among the three curves, with that of the behavioral curve ranking the second and the cognitive curve the greatest.

The implication from the results is that in year 1, to achieve the highest learning improvement,
more cognitive learner engagement is needed than affective and behavioral engagement; when
the medium and low learning improvement is achieved, there is the greatest affective learner
engagement whereas the lowest cognitive engagement.

B. Categorized learner engagement and PBL effectiveness in year 2

The trends of the relation between the three categorized learner engagement and learning
improvement in year 2 with moving average of 1 were shown in Figure 7.38 and the
corresponding polynomial regression information was shown in Table 7.34 below:

![Figure 7.38. Relation between categorized learner engagement and learning improvement in year 2.](image)

### Table 7.34. Polynomial Regression information for the relation between categorized learner engagement and learning improvement in year 2.

<table>
<thead>
<tr>
<th>Learner engagement</th>
<th>Model</th>
<th>$F$ Value</th>
<th>$P$ Value</th>
<th>R-Square</th>
<th>Root-MSE</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behavioral</td>
<td>$Y = 72.7258-0.09145X-0.23148X^2$</td>
<td>295.1779</td>
<td>&lt;0.0001</td>
<td>0.98828</td>
<td>1.26473</td>
<td>10</td>
</tr>
<tr>
<td>Cognitive</td>
<td>$Y = 65.7131+1.47113X-0.24152X^2$</td>
<td>8.86157</td>
<td>0.01618</td>
<td>0.74708</td>
<td>4.95115</td>
<td>9</td>
</tr>
<tr>
<td>Affective</td>
<td>$Y = 61.50447+5.14355X-1.00484X^2$</td>
<td>33.96215</td>
<td>0.0087</td>
<td>0.9577</td>
<td>2.59869</td>
<td>6</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.38, it can be found that the
quadratic model was suitable to be chosen for describing the relation between the three

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categorized learner engagement and learning improvement in year 2.

From Table 7.34, it can be seen that all the three quadratic models were statistically significant \((P<0.05)\). So these three models were good predictors of PBL effectiveness. The R-Square values of the three models were good, greater than 0.70, indicating that more than 70% of the variability in PBL effectiveness can be explained by the three models.

From Figure 7.38, it can be seen that, the curves of the three models demonstrated similar trends, with the Y value increasing with the decrease of the X value. However, it can be found that differences exist among the three curves. The differences were examined from the two extent of the Y value which was divided by the intersection points (point A) between behavioral and cognitive curves, as shown in Figure 7.38.

It can be seen that when the Y value is greater than 67.5, to achieve the same Y value, the X value of the affective curve is the smallest among the three curves, with that of the cognitive curve ranking the second and the behavioral curve the greatest; In addition, the greatest Y value is likely to be achieved by the behavioral curve other than the other two. When the Y value is below 67.5, to achieve the same Y value, the X value of the affective curve is the smallest among the three curves, with that of the behavioral curve ranking the second and the cognitive curve the greatest.

The implication from the results is that in year 2, to achieve the highest learning improvement, more behavioral learner engagement is needed than affective and cognitive engagement; when the medium and low learning improvement is achieved, there is the greatest affective learner engagement whereas the lowest cognitive engagement.

C. Categorized learner engagement and PBL effectiveness in year 3&4

The trends of the relation between the three categorized learner engagement and learning improvement in year 3 & 4 with moving average of 1 were shown in Figure 7.39 and the corresponding polynomial regression information was shown in Table 7.35 below:

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The Model of PBL Effectiveness in Engineering Design

From the mapping of the central point data shown in Figure 7.39, it can be found that the linear model was suitable to be chosen for describing the relation between the three categorized learner engagement and learning improvement in year 3 & 4.

From Table 7.35, it can be seen that all the three linear models were statistically significant ($P<0.05$). So these three models were good predictors of PBL effectiveness. The R-Square values of the models of cognitive and affective learner engagement were good, greater than 0.90, whereas the R-Square value of the model of behavioral learner engagement was not so good, less than 60%.

Table 7.35. Polynomial Regression information for the relation between categorized learner engagement and learning improvement in year 3&4.

<table>
<thead>
<tr>
<th>Learner engagement</th>
<th>Model</th>
<th>$F$ Value</th>
<th>$P$ Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behavioral</td>
<td>$Y = A + B1*X 2$</td>
<td>70.93165</td>
<td>7.85921</td>
<td>0.03102</td>
<td>0.56707</td>
<td>2.32408</td>
</tr>
<tr>
<td>Cognitive</td>
<td>96.12387-2.85698X</td>
<td>102.73729</td>
<td>1.60223E-4</td>
<td>0.95359</td>
<td>1.4915</td>
<td>7</td>
</tr>
<tr>
<td>Affective</td>
<td>81.51986-3.71644X</td>
<td>74.06646</td>
<td>0.001</td>
<td>0.94876</td>
<td>1.80649</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 7.39. Relation between categorized learner engagement and learning improvement in year 3 & 4.
From Figure 7.39, it can be seen that, the curves of the three models demonstrated similar trends, with the Y value increasing with the decrease of the x value. However, it is obvious that differences exist among the three curves. The differences were examined from the three extent of the Y value which was divided by the intersection points between the three curves (point A and B as shown in Figure 7.40):

![Diagram showing three stages in the relation between categorized learner engagement and learning improvement in year 3 & 4.]

It can be seen that when the Y value is greater than 67, to achieve the same Y value, the X value of the behavioral curve is the smallest among the three curves, and that of the cognitive curve is the greatest; when the Y value is lower than 62, to achieve the same Y value, the X value of the affective curve is the smallest, whereas that of the behavioral curve is the greatest; when the Y value is between 62 and 67, to achieve the same Y value, the X value of the affective curve is the smallest, whereas that of the cognitive curve is the greatest.

The implication from the results is that in year 3 & 4, to achieve high learning improvement, more behavioral learner engagement is needed than affective and cognitive engagement; when the medium learning improvement is achieved, there is more affective learner engagement than the other two; when the learning improvement is low, there is the most affective learner engagement yet the lowest behavioral learner engagement.

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D. Comparison of the relation between categorized learner engagement and PBL effectiveness across academic years

With the relation between categorized learner engagement and learning improvement being found out in each academic year, comparison was made between them respectively across academic years, as shown from Figure 7.41 to Figure 43:

Figure 7.41. Comparison of behavioral learner engagement across academic years.

Figure 7.42. Comparison of cognitive learner engagement across academic years.
In the relation between behavioral learner engagement and learning improvement across academic years, as shown in Figure 7.41, it can be seen that the general trend of the three curves is that the Y value increases with the decrease of the X value. It can be found that the Y value of year 1 and year 2 curves changes obviously with the change of the X value, while the curve of year 3 & 4 is much flatter and its Y value changes gradually with the change of the X value. The implication is that across academic years, the amount of behavioral learner engagement influences learning improvement in the way that more behavioral learner engagement may bring higher learning improvement. Comparatively, the extent of the influence of behavioral learner engagement on learning improvement in year 1 and year 2 is much greater than that in year 3 & 4.

In the relation between cognitive learner engagement and learning improvement across academic years, as shown in Figure 7.42, it can be seen that the general trend of the three curves is similar with that behavioral learner engagement, that is, the Y value increases with the decrease of the X value. In addition, the extent of the change of the Y value with the change of the X value is also similar across academic years. The implication is that across academic years, the amount of cognitive learner engagement influences learning improvement in the way that more cognitive learner engagement may bring higher learning improvement, and the extent of
its influence on learning improvement is similar across academic years.

In the relation between affective learner engagement and learning improvement across academic years, as shown in Figure 7.43, it can be seen that again the general trend of the three curves is that the Y value increases with the decrease of the x value. It can be found that the Y value of year 2 curve changes much greater with the change of the X value than that of year 1 and year 3 & 4 curves. The implication is that across academic years, the amount of affective learner engagement influences learning improvement in the way that more affective learner engagement may bring higher learning improvement. The extent of the influence of affective learner engagement on learning improvement in year 2 is much greater than that in year 1 and year 3 & 4.

On the other hand, when the curves in the three Figures, from Figure 7.41 to Figure 7.43, is compared at the same time, it can be found that to achieve the same amount of the Y value, the X value of affective learner engagement across academic years is smaller than that of behavioral learner engagement, which is further smaller than that of cognitive learner engagement. The implication is that more affective learner engagement is required across academic years than the amount of the other two categorized learner engagement when a certain amount of learning improvement is to be achieved.

7.5.5 The Relation between Other Parameters and PBL Effectiveness

7.5.5.1 The Relation between Team Dynamics and PBL Effectiveness

A. Team dynamics and learning improvement in year 1

The trends of the relation between team dynamics and learning improvement in year 1 with moving average of 1 and 2 were shown in Figure 7.44 and the corresponding polynomial regression information was shown in Table 7.36 below:
Table 7.36. Polynomial Regression information for the relation between team dynamics and learning improvement in year 1.

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model</th>
<th>$F$ Value</th>
<th>$P$ Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =1</td>
<td>(Y = A + B1<em>X + B2</em>X^2)</td>
<td>33.86601</td>
<td>&lt;0.0001</td>
<td>0.83897</td>
<td>2.39765</td>
<td>16</td>
</tr>
<tr>
<td>MA =2</td>
<td>84.47811-2.03605X+0.03854X^2</td>
<td>15.04148</td>
<td>0.00195</td>
<td>0.78993</td>
<td>2.89464</td>
<td>11</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.44, it can be found that the quadratic model was suitable to be chosen for describing the relation between team dynamics and learning improvement in year 1. It can be seen that the curves of the two models overlapped to much extent and demonstrated similar trends, that is, the Y value increased with the decrease of the X value.

From Table 7.36, it can be found that both the two quadratic models were statistically significant ($P<0.01$). So the two models were good predictors of PBL effectiveness. The R-Square values of the two models were good, greater than 0.70, indicating that more than 70% of the variability in PBL effectiveness can be explained by the two models.

The implication of the results is that in year 1, learning improvement is influenced by the degree
of team dynamics, with higher degree of team dynamics bringing greater learning improvement.

B. The relation between team dynamics and learning improvement in year 2

The trends of the relation between team dynamics and learning improvement in year 2 with moving average of 1 and 2 were shown in Figure 7.45 and the corresponding polynomial regression information was shown in Table 7.37 below:

![Figure 7.45. Relation between team dynamics and learning improvement in year 2.](image)

<table>
<thead>
<tr>
<th>MA</th>
<th>Model</th>
<th>$F$ Value</th>
<th>$P$ Value</th>
<th>R-Square</th>
<th>Root-MSE</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =1 Linear</td>
<td>$(Y = A + B1*X)$</td>
<td>2.50266</td>
<td>0.15767</td>
<td>0.26336</td>
<td>3.82816</td>
<td>9</td>
</tr>
<tr>
<td>MA =2 Linear</td>
<td>$68.49023 - 0.4021X$</td>
<td>8.72558</td>
<td>0.02548</td>
<td>0.59255</td>
<td>1.76438</td>
<td>8</td>
</tr>
<tr>
<td>MA =1 Quadratic</td>
<td>$107.21685 - 5.29694X + 0.1505X^2$</td>
<td>2.0211</td>
<td>0.21329</td>
<td>0.40252</td>
<td>3.7239</td>
<td>9</td>
</tr>
<tr>
<td>MA =2 Quadratic</td>
<td>$76.66766 - 1.37368X + 0.02699X^2$</td>
<td>4.3541</td>
<td>0.08035</td>
<td>0.63526</td>
<td>1.82868</td>
<td>8</td>
</tr>
</tbody>
</table>

From the mapping of the central point data in Figure 7.45 it can be seen that the trends of curves were not obvious. Thus, comparisons were made between types of linear and quadratic curves and the information about how well the data of year 2 were fit by each type of curve was shown in Table 7.37.
From Table 7.37, it can be found that the $F$ test values for the linear model of moving average of 1 and the quadratic models of moving average 1 and 2 were nonsignificant ($P>0.05$); only the linear model of moving average of 2 was statistically significant ($P<0.05$), indicating that it was a good predictor for PBL effectiveness. None of the linear and quadratic models had R-Square values greater than 0.7, among which the R-Square value of the linear model of moving average 2 ranked the second highest; in addition, its MSE was the smallest for the four models. Thus, the criteria which were used here for comparison all indicated the linear model of moving average of 2 was relatively superior fit to those for other types of curves, as shown in Figure 7.45.

From Figure 7.45 it can be seen that the Y value increased with the decrease of the x value, indicating that in year 2 learning improvement is likely to be influenced by the degree of team dynamics, and the higher degree of team dynamics may bring the greater learning improvement.

C. The relation between team dynamics and learning improvement in year 3 & 4

The trends of the relation between team dynamics and learning improvement in year 3 & 4 with moving average of 1 and 2 were shown in Figure 7.46 and the corresponding polynomial regression information was shown in Table 7.38 below:

![Figure 7.46. Relation between team dynamics and learning improvement in year 3 & 4.](image)
Table 7.38. Polynomial Regression information for the relation between team dynamics and learning improvement in year 3 & 4.

<table>
<thead>
<tr>
<th>MA</th>
<th>Model</th>
<th>F Value</th>
<th>P Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =1 Linear</td>
<td>$Y = A + B_1*X$</td>
<td>8.31653</td>
<td>0.01373</td>
<td>0.40935</td>
<td>3.50681</td>
<td>14</td>
</tr>
<tr>
<td>MA =2 Linear</td>
<td>$Y = A + B_1*X$</td>
<td>5.40822</td>
<td>0.059</td>
<td>0.47406</td>
<td>3.04133</td>
<td>8</td>
</tr>
<tr>
<td>MA =1 Quadratic</td>
<td>$Y = A + B_1<em>X + B_2</em>X^2$</td>
<td>4.63925</td>
<td>0.03459</td>
<td>0.45755</td>
<td>3.5101</td>
<td>14</td>
</tr>
<tr>
<td>MA =2 Quadratic</td>
<td>$Y = A + B_1<em>X + B_2</em>X^2$</td>
<td>3.82428</td>
<td>0.09825</td>
<td>0.6047</td>
<td>2.88837</td>
<td>8</td>
</tr>
</tbody>
</table>

From the mapping of the central point data in Figure 7.46 it can be seen that the trends of curves were not obvious. Thus, like in year 2, comparisons were made between types of linear and quadratic curves and the information about how well the data of year 3 & 4 were fit by each type of curve was shown in Table 7.38.

From Table 7.38, it can be found that the $F$ test values for the linear model of moving average of 1 and the quadratic models of moving average 1 were statistically significant ($P<0.05$), indicating that these two models were the good predictor for PBL effectiveness. None of the linear and quadratic models of the moving average of 1 had R-Square values greater than 0.5, with the R-Square value of the former model slightly lower than that of the latter model. The MSE values of the two models were also of similar value. Thus, the criteria which were used here for comparison indicated both the linear model and the quadratic model of moving average of 1 was relatively superior fit to those for other types of curves, with the linear model slightly better in the $P$ value while the quadratic model slightly better in goodness of fitting. In this study, considering its slightly better fitting, the quadratic model was chosen to represent the relation between team dynamics and learning improvement in year 3 & 4, as shown in Figure 7.46.

From Figure 7.46 it can be seen that the Y value increased with the decrease of the x value, indicating that in year 3 & 4, learning improvement is likely to be influenced by the degree of team dynamics, and the higher degree of team dynamics may bring the greater learning improvement.
D. Comparison of the relation between team dynamics and learning improvement across academic years

With the relation between team dynamics and learning improvement being found out in each academic year, comparison was made between them across academic years, as shown in Figure 7.47:

![Graph showing comparison of the relation between team dynamics and learning improvement across academic years.](image)

Figure 7.47. Comparison of the relation between team dynamics and learning improvement across academic years.

From Figure 7.47 it can be seen that in the general trend of the three curves is that the Y value increases with the decrease of the X value across academic years. To achieve the same amount of Y value, when the Y value is higher than 65, the X value of year 2 is the smallest among the three curves, with that of year 3 & 4 ranking the second and year 2 ranking the lowest; when the Y value is lower than 62.5, the X value of year 1 is the smallest, with that of year 2 ranking the second and year 3 & 4 ranking the lowest.

The implication from the results is that across the academic years, learning improvement is likely to change with the change of team dynamics, with the greater degree of team dynamics bringing the higher learning improvement. To achieve the same amount of high learning improvement, better team dynamics is required in year 2 than in year 3 & 4 and year 1; when the learning improvement is of the same medium or low amount, it is likely that the team dynamics in year 1 is better than the other two, and that in year 3 & 4 would be the worst.
7.5.5.2 The Relation between Design Problems and PBL Effectiveness

A. Design problems and learning improvement in year 1

The trends of the relation between design problems and learning improvement in year 1 with moving average of 1 and 2 were shown in Figure 7.48 and the corresponding polynomial regression information was shown in Table 7.39 below:

![Figure 7.48. Relation between design problem and learning improvement in year 1.](image)

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model</th>
<th>$F$ Value</th>
<th>$P$ Value</th>
<th>R-Square</th>
<th>Root-MSE</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =1</td>
<td>$Y = A + B1<em>X + B2</em>X^2$</td>
<td>331.18917</td>
<td>3.02746E-4</td>
<td>0.99549</td>
<td>0.58667</td>
<td>6</td>
</tr>
<tr>
<td>MA =2</td>
<td>89.59591-6.60644X+0.3196X^2</td>
<td>43.09765</td>
<td>7.03872E-4</td>
<td>0.94517</td>
<td>1.34151</td>
<td>8</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.48, it was obvious that the quadratic model was suitable to be chosen for describing the relation between design problem and PBL effectiveness in year 1. From Figure 7.48, it can be seen that the two moving average curves demonstrated similar trends, with the Y value decreasing with the increase of the X value.

From Table 7.39, it can be seen that both the two quadratic models were statistically significant.
(P < 0.0001). So these two models were very good predictors of PBL effectiveness. The R-Square values of the two models were greater than 0.9, indicating that more than 90% of the variability in PBL effectiveness can be explained by the two models.

The implication from the trends is that in year 1, when the design problem is better, more learning improvement is likely to be made.

B. Design problems and learning improvement in year 2

The trends of the relation between design problems and learning improvement in year 2 with moving average of 1 and 2 were shown in Figure 7.49 and the corresponding polynomial regression information was shown in Table 7.40 below:

![Figure 7.49. Relation between design problem and learning improvement in year 2.](image)

**Table 7.40. Polynomial Regression information for the relation between design problem and learning improvement in year 2.**

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model (Y = A + B1*X)</th>
<th>F Value</th>
<th>P Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =1</td>
<td>83.53669-3.64782X</td>
<td>98.99895</td>
<td>5.73055E-4</td>
<td>0.96116</td>
<td>1.53369</td>
<td>6</td>
</tr>
<tr>
<td>MA =2</td>
<td>77.71451-2.69101X</td>
<td>124.53143</td>
<td>3.67024E-4</td>
<td>0.96888</td>
<td>1.00878</td>
<td>6</td>
</tr>
</tbody>
</table>
From the mapping of the central point data shown in Figure 7.49, it was obvious that the linear model was suitable to be chosen for describing the relation between design problem and PBL effectiveness in year 2. From Figure 7.49, it can be seen that the two moving average curves demonstrated similar trends, with the Y value decreasing with the increase of the X value.

From Table 7.40, it can be seen that both of the two linear models were statistically significant ($P < 0.0001$). So these two models were very good predictors of PBL effectiveness. The R-Square values of the two models were greater than 0.9, indicating that more than 90% of the variability in PBL effectiveness can be explained by the two models.

The implication from the trends is that in year 2, when the design problem is better, more learning improvement is likely to be made.

C. Design problems and learning improvement in year 3 & 4

The trends of the relation between design problems and learning improvement in year 3 & 4 with moving average of 1 and 2 were shown in Figure 7.50 and the corresponding polynomial regression information was shown in Table 7.41 below:

![Figure 7.50. Relation between design problem and learning improvement in year 3 & 4.](image-url)
From the mapping of the central point data shown in Figure 7.50, it was obvious that the linear model was suitable to be chosen for describing the relation between design problem and PBL effectiveness in year 3 & 4. From Figure 7.50, it can be seen that the two moving average curves demonstrated similar trends, with the Y value decreasing with the increase of the X value.

From Table 7.41, it can be seen that both the two models were statistically significant ($P < 0.0001$). So these two models were very good predictors of PBL effectiveness. The R-Square values of the two models were greater than 0.9, indicating that more than 90% of the variability in PBL effectiveness can be explained by the two models.

The implication from the results is that in year 3 & 4, better design problem is likely to bring higher learning improvement.

D. The relation between design problems and learning improvement across academic years

With the relation between tutorial and learning improvement being found out in each academic year, comparison was made between them. For the sake of consistency, curves of moving average of 1 ($DT = 1$, $DS = 1$) were chosen for comparison across academic years, as shown in Figure 7.51:
From Figure 7.51 it can be found that the general trend of the three curves across academic years is that with the increase of the Y value, the X value deceases, indicating that across academic years, better design problem can bring higher learning improvement. It can also be found that the curve of year 3 & 4 is flatter than that of year 1 and year 2, that is, the change of the Y value in year 3 curve is less great than that in year 1 and year 2, indicating that the influence of design problem in year 3 & 4 is not so great as that in year 1 and year 2.

### 7.5.5.3 The Relation between Tutorial and PBL Effectiveness

A. Tutorial and learning improvement in year 1

The trends of the relation between tutorial and learning improvement in year 1 with moving average of 1 and 2 were shown in Figure 7.52 and the corresponding polynomial regression information was shown in Table 7.42 below:
From the mapping of the central point data shown in Figure 7.52, it was obvious that the linear model was suitable to be chosen for describing the relation between tutorial and PBL effectiveness in year 1. From Figure 7.52 it can be seen that the two moving average curves demonstrated similar trends, with the Y value decreasing with the increase of the X value.

From Table 7.42, it can be seen that both the two models were statistically significant ($P < 0.05$). So these two models were good predictors of PBL effectiveness. The R-Square values of the two models were greater than 0.9, indicating that more than 90% of the variability in PBL effectiveness can be explained by the two models.

The implication from the trends is that in year 1, the more support the tutorial is provided, the
higher learning improvement is likely to be achieved.

B. Tutorial and learning improvement in year 2

The trends of the relation between tutorial and learning improvement in year 2 with moving average of 1 and 2 were shown in Figure 7.53 and the corresponding polynomial regression information was shown in Table 7.43 below:

![Figure 7.53. Relation between tutorial and learning improvement in year 2.](image)

Table 7.43. Polynomial Regression information for the relation between tutorial and learning improvement in year 2.

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model (Y = A + B1*X)</th>
<th>F Value</th>
<th>P Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =1</td>
<td>72.49516-1.49706X</td>
<td>121.21908</td>
<td>1.07581E-4</td>
<td>0.96039</td>
<td>0.88121</td>
<td>7</td>
</tr>
<tr>
<td>MA =2</td>
<td>75.84608-1.90055X</td>
<td>79.31463</td>
<td>&lt;0.0001</td>
<td>0.9189</td>
<td>1.65302</td>
<td>9</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.53, it was obvious that the linear model was suitable to be chosen for describing the relation between design problem and PBL effectiveness in year 2. From Figure 7.53 it can be seen that the two moving average curves demonstrated similar trends, with the Y value decreasing with the increase of the X value.
From Table 7.43, it can be seen that both the two models were statistically significant ($P < 0.0001$). So these two models were very good predictors of PBL effectiveness. The R-Square values of the two models were greater than 0.9, indicating that more than 90% of the variability in PBL effectiveness can be explained by the two models.

The implication from the trends is that in year 2, the more support the tutorial is provided, the higher learning improvement is likely to be achieved.

C. Tutorial and learning improvement in year 3 & 4

The trends of the relation between tutorial and learning improvement in year 3 & 4 with moving average of 1 and 2 were shown in Figure 7.54 and the corresponding polynomial regression information was shown in Table 7.44 below:

![Figure 7.54. Relation between tutorial and learning improvement in year 3 & 4.](image_url)
Table 7.44. Polynomial Regression information for the relation between tutorial and learning improvement in year 3 & 4.

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model ((Y = A + B1<em>X + B2</em>X^2))</th>
<th>(F) Value for Model</th>
<th>(P) Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =1</td>
<td>106.50074 -17.60455X + 2.4226X^2</td>
<td>10.32149</td>
<td>0.04336</td>
<td>0.91167</td>
<td>2.33266</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>-0.10875X^3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MA =2</td>
<td>99.692 -13.25299X + 1.63694X^2</td>
<td>21.3852</td>
<td>0.00279</td>
<td>0.9277</td>
<td>1.57922</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>-0.06654X^3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.54, it was obvious that the quadratic model was suitable to be chosen for describing the relation between tutorial and PBL effectiveness in year 3 & 4. From Figure 7.54, it can be seen that the general trend of the two curves was that the Y value decreased with the increase of the X value, with a standstill period between point A and B, where the Y value did not change with the increase of the X value.

From Table 7.44, it can be seen that both of the models were statistically significant \((P < 0.05)\), indicating that they were good predictors of PBL effectiveness; in addition, both of the R-Square values were greater than 0.9, indicating that more than 90% of the variability in PBL effectiveness can be explained by the two models.

The implication from the results is that in year 3 & 4, higher learning improvement is likely to be made with more support from tutorial, yet when the support from tutorial is not great enough, there would be a standstill stage where further learning improvement is hard to be achieved.

D. The relation between tutorial and learning improvement across academic years

With the relation between tutorial and learning improvement being found out in each academic year, comparison was made between them. For the sake of consistency, curves of moving average of 2 \((DT = 2, DS = 2)\) were chosen for comparison across academic years, as shown in Figure 7.55:
From Figure 7.55 it can be found that the general trend of the three curves across academic years is that with the increase of the Y value, the X value deceases, indicating that across academic years, more helpful tutorial can bring higher learning improvement.

It can also be found that to achieve the same Y value, the X values of the three curves are different. To achieve the Y value greater than about 65, the X value of year 2 and year 3 & 4 are the same, both smaller than that of year 1; to achieve the Y value smaller than about 65, the X value of year 2 is smaller than that of year 1, which is further smaller than that of year 3 & 4.

The implication is that to achieve the same high learning improvement, more support from tutorial is called for in year 2 and year 3 & 4 than that in year 1; by comparison, less support of tutorial in year 3 & 4 than that in year 1 and year 2 can bring the same medium and low learning improvement.

### 7.5.5.4 The Relation between Lecture and PBL Effectiveness

A. Lecture and learning improvement in year 1

The trends of the relation between lecture and learning improvement in year 1 with moving average of 1 and 2 were shown in Figure 7.56 and the corresponding polynomial regression
information was shown in Table 7.45 below:

![Graph showing the relation between lecture and learning improvement in year 1.](image)

**Table 7.45. Polynomial Regression information for the relation between lecture and learning improvement in year 1.**

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model</th>
<th>$F$ Value</th>
<th>$P$ Value For Model</th>
<th>$P$ Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA = 1</td>
<td>$81.81809 - 2.1734X$</td>
<td>57.30231</td>
<td>&lt;0.0001</td>
<td>0.86426</td>
<td>3.01128</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>MA = 2</td>
<td>$80.07026 - 1.95578X$</td>
<td>69.662</td>
<td>&lt;0.0001</td>
<td>0.88559</td>
<td>2.45764</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.56, it was obvious that the linear model was suitable to be chosen for describing the relation between lecture and PBL effectiveness in year 1. From Figure 7.56 it can be seen that the two moving average curves demonstrated similar trends, with the Y value decreasing with the increase of the X value.

From Table 7.45, it can be seen that both the two models were statistically significant ($P < 0.0001$). So these two models were good predictors of PBL effectiveness. The R-Square values of the two models were greater than 0.8, indicating that more than 80% of the variability in PBL effectiveness can be explained by the two models.
The implication from the trends is that in year 1, the more useful the lecture is, the higher learning improvement is likely to be achieved.

B. Lecture and learning improvement in year 2

The trends of the relation between lecture and learning improvement in year 2 with moving average of 1 and 2 were shown in Figure 7.57 and the corresponding polynomial regression information was shown in Table 7.46 below:

![Figure 7.57. Relation between lecture and learning improvement in year 2.](image)

Table 7.46. Polynomial Regression information for the relation between lecture and learning improvement in year 2.

<table>
<thead>
<tr>
<th>MA</th>
<th>Model</th>
<th>F Value For Model</th>
<th>P Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =1</td>
<td>Quadratic</td>
<td>120.12839 -11.95214X + 0.58041X^2</td>
<td>19.25741</td>
<td>0.00448</td>
<td>0.8851</td>
<td>1.9846</td>
</tr>
<tr>
<td>MA =2</td>
<td>Quadratic</td>
<td>82.38673 -3.21944X + 0.10016X^2</td>
<td>17.73295</td>
<td>0.00115</td>
<td>0.81595</td>
<td>2.19784</td>
</tr>
<tr>
<td>MA =1</td>
<td>Cubic</td>
<td>220.15768-48.16095X+4.76282X^2-0.1549X^3</td>
<td>40.67423</td>
<td>0.00187</td>
<td>0.96826</td>
<td>1.16618</td>
</tr>
<tr>
<td>MA =2</td>
<td>Cubic</td>
<td>135.9093-21.59422X+2.05354X^2-0.06511X^3</td>
<td>37.00736</td>
<td>1.1554E-4</td>
<td>0.94069</td>
<td>1.33379</td>
</tr>
</tbody>
</table>
From the mapping of the central point data shown in Figure 7.57, it can be found that the trends of the moving average curves were not very obvious. Thus, comparisons between types of quadratic and cubic curves were made and the information about how well the data of year 2 are fit by each type of curve was shown in the table 7.46:

From Table 7.46, it can be seen that the $F$ test values for both types of models were statistically significant ($P < 0.01$), indicating that they were good predictors of PBL effectiveness. By comparison, the R-Square values for the cubic model were greater than those for the quadratic model, with the former greater than 0.9 and the latter less than 0.9, indicating that more than 90% of the variability in PBL effectiveness can be explained by the cubic model, while less than 90% of the variability in PBL effectiveness can be explained by the quadratic model. In addition, the MSE values for the cubic model are smaller than those for the quadratic model. The criteria which were used here for comparison all indicated that the cubic curve was superior fit to the quadratic curve, thus the cubic curve was chosen to represent the relation between lecture and PBL effectiveness in year 2, as shown in Figure 7.57.

From Figure 7.57, it can be seen that the general trend of the two curves was that the Y value decreased with the increase of the X value, with a standstill period between point A and B, where the Y value did not change with the increase of the X value. The implication from the results is that in year 2, higher learning improvement is likely to be made with more support from lecture, yet when the support from lecture is not great enough, there would be a standstill stage where further learning improvement is hard to be achieved.

C. Lecture and learning improvement in year 3 & 4

The trends of the relation between lecture and learning improvement in year 3 & 4 with moving average of 1 and 2 were shown in Figure 7.58 and the corresponding polynomial regression information was shown in Table 7.47 below:
The Model of PBL Effectiveness in Engineering Design

Table 7.47. Polynomial Regression information for the relation between lecture and learning improvement in year 3 & 4.

<table>
<thead>
<tr>
<th>Moving average (MA)</th>
<th>Model</th>
<th>$F$ Value</th>
<th>$P$ Value</th>
<th>R-Square</th>
<th>Root-MSE</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA =1</td>
<td>$Y = A + B1X + B2X^2 + B3X^3$</td>
<td>17.34827</td>
<td>0.00449</td>
<td>0.91235</td>
<td>1.72749</td>
<td>9</td>
</tr>
<tr>
<td>MA =2</td>
<td>-38.7766+33.65349X-3.54675X^2+0.11975X^3</td>
<td>5.636</td>
<td>0.02777</td>
<td>0.70721</td>
<td>3.04173</td>
<td>11</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.58, it was obvious that the cubic model was suitable to be chosen for describing the relation between lecture and PBL effectiveness in year 3 & 4. From Figure 7.58, it can be seen that the two moving average curves demonstrated similar trends.

From Table 7.47, it can be seen that both the two cubic models were statistically significant ($P<0.05$). So these two models were good predictors of PBL effectiveness. The R-Square values of the two models were greater than 0.7, indicating that more than 70% of the variability in PBL effectiveness can be explained by the two models.

Figure 7.58. Relation between lecture and learning improvement in year 3 & 4.
From Figure 7.58 it can be found that when the X value is small (smaller than 7 or 8 at point A1 & A2), or great enough (greater than 12 or 13 at point of B1 & B2), the Y value increases with the increase of the X value; however, when the X value is within the middle range from the relative maximum point A to the relative minimum point B, that is, from 7 or 8 to 11 or 12, the Y value decreases with the increase of the X value. The implication from the trend is that more learning improvement is likely to be achieved with less support from lecture, except when the support of lecture is of medium extent, where learning improvement is likely to be improved with the increasing support of lecture.

D. The relation between lecture and learning improvement across academic years

With the relation between lecture and learning improvement being found out in each academic year, comparison was made between them. For the sake of consistency, curves of moving average of 1 (DT = 1, DS = 1) were chosen for comparison across academic years, as shown in Figure 7.59:

![Figure 7.59. Comparison between the relation between lecture and learning improvement across academic years.](image)

From the trends of the curves in Figure 7.59, it can be seen that to achieve the same Y value, the X values of the three curves are different. The differences can be examined from the perspective of three stages of the Y value: to achieve the same Y value greater than about 67.5, the X value of year 1 is smaller than that of year 2, which is further smaller than that of year 3 & 4; to
achieve the same Y value lower than 59, the X value of year 3 is smaller than that of year 1, which is further smaller than that of year 2; to achieve the same Y value between 67.5 and 59, the X value of year 2 is smaller than that of year 1, the two of which could be either smaller or greater than that of year 3 & 4.

In addition, it can be found that the standstill point of year 2 and the relative maximum point of year 3 & 4 occur at the same X value; from the X value of the relative minimum point C of year 3 & 4, the Y value began to decrease in year 2 whereas increase in year 3 & 4.

The implication from the results is that to achieve the same high learning improvement, more support from lecture is required in year 1 and year 2 than in year 3 & 4; to achieve the same medium learning improvement, more support from lecture is needed in year 2 than in year 1, yet for year 3 & 4, the support from lecture tends to be very flexible; finally, more support from lecture can cause low learning improvement in year 3 & 4, and by contrast, less support from lecture can cause the same low learning improvement in year 1 and year 2.

In addition, it should be noted that the same amount of support from lecture which can bring the relative optimal learning improvement in year 3 & 4 (point A in Figure 7.59) is likely to cause the relative lowest learning improvement in year 2 (point B in Figure 7.59); concerning with the amount of support from lecture which cause the relative lowest learning improvement in year 3 & 4 (point C in Figure 7.59), the less amount of support from lecture may bring increase in learning improvement in year 3 & 4; by contrast, the same less amount of support from lecture may cause further decrease in learning improvement in year 2.

7.5.6 The Influence of Previous Industrial Experience on the PBL Effectiveness Model

7.5.6.1 The Influence of Industrial Experience on the Relation between SDL Time and Learning Improvement

A. Influence on the relation between SDL time and PBL improvement in year 1

The trends between SDL time and learning improvement under the influence of industrial
experience in year 1 with the moving average of 15 (\( DT = 15, DS = 5 \)) were shown in Figure 7.60 and the corresponding polynomial regression information was shown in Table 7.48 below:

![Figure 7.60. Influence of industrial experience on the relation between SDL time and learning improvement in year 1.](image)

Table 7.48. Polynomial Regression information for the influence on the relation between SDL time and learning improvement in year 1.

<table>
<thead>
<tr>
<th>Industrial experience (IE)</th>
<th>Model</th>
<th>( F ) Value</th>
<th>( P ) Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>With IE (-202.65821+21.94205X-0.62171X^2+0.00732^3-3.06097E-5X^4)</td>
<td>18.07365</td>
<td>4.53431E-4</td>
<td>0.90037</td>
<td>1.59737</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Without IE (38.10283+0.99644X-0.00837X^2)</td>
<td>63.54295</td>
<td>&lt;0.0001</td>
<td>0.90077</td>
<td>1.94339</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.60, it was obvious that the quartic and quadratic models were suitable to be chosen for describing respectively the relation between SDL time and PBL effectiveness with and without the influence of industrial experience in year 1.

From Table 7.48, it can be seen that both the two models were statistically significant (\( P <0.0001 \)). So these two models were good predictors of PBL effectiveness. The R-Square values of the two models were greater than 0.9, indicating that more than 90% of the variability in PBL
effectiveness can be explained by the two models.

The maximum point of the quadratic curve (point A as shown in Figure 7.60) was found, which was at

\[ X_{m1} = \frac{-b_1}{2b_2} = \frac{-0.99644}{2(-0.00837)} = 60 \]

The maximum and the relative maximum points of the quartic curve (point C & D as shown in Figure 7.60) were found at 36% and 85% SDL time respectively. It can be found that the Y values at point C and D are higher than that at point A. In addition, it can be seen that the SDL time for achieving the maximum point of the quadratic curve (point A) is of the same amount of SDL time for getting the relative minimum point of the quartic curve (point B).

The indication from the results is that in year 1, for the students without industrial experience, the amount of 60% SDL time can bring optimal learning improvement; there is not likely to be any further increase at a greater amount of SDL time. For the students with industrial experience, the amount of 36% and 85% SDL time would respectively bring the optimal and relative optimal learning improvement; the amount of SDL time that brings the optimal improvement for the students without industrial experience would cause the relative lowest learning improvement for the students with industrial experience. In addition, the optimal learning improvement achieved by students with industrial experience tends to be higher than that by students without industrial experience.

B. Influence on the relation between SDL and PBL improvement in year 3 & 4

The trends between SDL time and learning improvement under the influence of industrial experience in year 3 & 4 with the moving average of 15 (DT = 15, DS = 5) were shown in Figure 7.61 and the corresponding polynomial regression information was shown in Table 7.49 below:
Figure 7.61. Influence of industrial experience on the relation between SDL time and learning improvement in year 3 & 4.

Table 7.49. Polynomial Regression information for the influence on the relation between SDL time and learning improvement in year 3 & 4.

<table>
<thead>
<tr>
<th>Industrial experience (IE)</th>
<th>Model</th>
<th>$F$ Value</th>
<th>$P$ Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>With IE</td>
<td>$Y = -3.27158 + 1.80731X - 0.01198X^2$</td>
<td>5.35257</td>
<td>0.05719</td>
<td>0.68163</td>
<td>1.19076</td>
<td>8</td>
</tr>
<tr>
<td>Without IE</td>
<td>$Y = -17.67973 + 2.48295X - 0.01711X^2$</td>
<td>10.004</td>
<td>0.04708</td>
<td>0.86961</td>
<td>1.32915</td>
<td>6</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.61, it can be seen that the quadratic models were suitable to be chosen for describing the relation between SDL time and PBL effectiveness with and without the influence of industrial experience in year 3 & 4.

From Table 7.49, it can be seen that the $F$ test for the model with industrial experience was nonsignificant ($P > 0.05$), and its R-Square value is less than 0.7. The $F$ test for the model without industrial experience was statistically significant ($P < 0.05$), indicating that it was a predictor of PBL effectiveness; and its R-Square was greater than 0.8, indicating that more than 80% of the variability in PBL effectiveness can be explained by it.

Bearing in mind the nonsignificant $P$ value of model with industrial experience, the comparison
between the two models was made.

The maximum points of the two models were found, which were at

\[ X_{m1} = -\frac{-b_1}{2}\frac{b_2}{2} = -\frac{-1.80731}{2}\frac{(-0.01198)}{2} = 75 \]

\[ X_{m2} = -\frac{-b_1}{2}\frac{b_2}{2} = -\frac{-2.48295}{2}\frac{(-0.01711)}{2} = 73 \]

It can be found that the two models shared similar amount of SDL time for their maximum Y values. In addition, the maximum Y value of the model without industrial experience was higher than that of the model with industrial experience. The implication from the results is that in year 3 & 4, both students with and without industrial experience can achieve their optimal learning improvement with similar amount of SDL time. By comparison, the learning improvement achieved by students without industrial experience is higher than that by students with industrial experience, which is just the opposite of the outcome in year 1.

7.5.6.2 The Influence of Industrial Experience on the Relation between Learner Engagement and Learning Improvement

A. Influence on the relation between learner engagement and learning improvement in year 1
The trends between SDL time and learning improvement under the influence of industrial experience in year 1 with the moving average of 2 (DT = 2, DS = 1) were shown in Figure 7.62 and the corresponding polynomial regression information was shown in Table 7.50:
Table 7.50. Polynomial Regression information for the influence on the relation between learner engagement and learning improvement in year 1.

<table>
<thead>
<tr>
<th>Industrial experience (IE)</th>
<th>Model</th>
<th>$F$ Value</th>
<th>$P$ Value</th>
<th>R-Square (COD)</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>With IE</td>
<td>87.55364-1.50114X</td>
<td>21.82653</td>
<td>0.00342</td>
<td>0.78438</td>
<td>2.08235</td>
<td>8</td>
</tr>
<tr>
<td>Without IE</td>
<td>83.58475-1.25003X</td>
<td>37.04292</td>
<td>&lt;0.0001</td>
<td>0.74022</td>
<td>3.43673</td>
<td>15</td>
</tr>
</tbody>
</table>

From the mapping of the central point data shown in Figure 7.62, it can be found that the linear models were suitable to be chosen for comparing the relation between learner engagement and PBL effectiveness with and without the influence of industrial experience in year 1.

From Table 7.50, it can be seen that both the two models were statistically significant ($P < 0.01$). So these two models were good predictors of PBL effectiveness. The R-Square values of the two models were greater than 0.7, indicating that more than 70% of the variability in PBL effectiveness can be explained by the two models.

It can be seen from Figure 7.62 that both curves demonstrated the same trend, with the Y value increasing with the decrease of the X value, and the maximum Y value of the curve with
industrial experience is greater than that of the curve without industrial experience.

Further differences can be found from the two extent of the Y value which was divided by the intersection point (point A) between the two curves, as shown in Figure 7.62. It can be seen that when the Y value is greater than 65, to achieve the same Y value, the X value of the curve without industrial experience is smaller than that of the curve with industrial experience; when the Y value is below 65, to achieve the same Y value, the X value of the curve with industrial experience is smaller than the curve without industrial experience.

The implication from the results is that in year 1, for both the students with and without industrial experience, the higher improvement can be achieved with more learning engagement. By comparison, the optimal learning improvement achieved by students with industrial experience is higher than that achieved by students without industrial experience. To achieve high learning improvement, more learning engagement is need for students without industrial experience than students with industrial experience; to make medium and low learning improvement, less learning engagement in students without industrial experience is likely to be needed than students with industrial experience.

B. Influence on the relation between learner engagement and learning improvement in year 3 & 4

The trends between SDL time and learning improvement under the influence of industrial experience in year 3 & 4 with the moving average of 2 (DT = 2, DS = 1) were shown in Figure 7.63 and the corresponding polynomial regression information was shown in Table 7.51 below:
From the mapping of the central point data shown in Figure 7.63, it can be found that the linear models were suitable to be chosen for comparing the relation between learner engagement and PBL effectiveness with and without the influence of industrial experience in year 1.

From Table 7.51, it can be seen that both the two models were statistically significant ($P<0.01$). So these two models were good predictors of PBL effectiveness. The R-Square values of the two models were greater than 0.8, indicating that more than 80% of the variability in PBL effectiveness can be explained by the two models.

It can be seen from Figure 7.63 that both curves demonstrated the same trend, with the Y value increasing with the decrease of the X value, and the maximum Y value of the curve without

<table>
<thead>
<tr>
<th>Industrial experience (IE)</th>
<th>Model ($Y = A + B1 \times X$)</th>
<th>$F$ Value</th>
<th>$P$ Value</th>
<th>R-Square $R^2$</th>
<th>Root-MSE (SD)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>With IE</td>
<td>86.15368-1.41346X</td>
<td>69.25837</td>
<td>&lt;0.0001</td>
<td>0.87383</td>
<td>2.03102</td>
<td>12</td>
</tr>
<tr>
<td>Without IE</td>
<td>94.48485-1.56309X</td>
<td>37.77644</td>
<td>0.00866</td>
<td>0.92643</td>
<td>0.80421</td>
<td>5</td>
</tr>
</tbody>
</table>

**Table 7.51.** Polynomial Regression information for the influence on the relation between learner engagement and learning improvement in year 3 & 4.

The Model of PBL Effectiveness in Engineering Design
industrial experience is greater than that of the curve with industrial experience. In addition, at the same X value, the Y value of the curve without industrial experience is always greater than that of the curve with industrial experience. On the other hand, to achieve the same Y value, the X value of the curve with industrial experience is always smaller than that of the curve without industrial experience.

The implication from the results is that in year 3 & 4, higher learning improvement can be achieved with greater learning engagement. The optimal learning improvement achieved by students without industrial experience is higher than that of the students with industrial experience. In addition, when the same amount of learner engagement is exerted, the learning improvement of students without industrial experience is always higher that that made by students with industrial experience. On the other hand, to achieve the same amount of learning improvement, the learner engagement exerted by student with industrial experience is greater than that exerted by student without industrial experience.

7.6 DISCUSSIONS AND IMPLICATIONS

7.6.1 SDL Time, Learner Engagement and PBL Effectiveness

From the findings in section 7.5, the following points related to SDL time, learner engagement and PBL effectiveness can be summarized:

1) SDL time is an important parameter of PBL effectiveness. No matter how much learner engagement is made, there always exists an optimal amount of SDL time which is correlated with an optimal learning outcome.

2) Generally speaking, learner engagement is positively correlated with the learning outcomes in PBL, with more learner engagement bringing higher learning outcomes. However, in year 1, when learner engagement reaches a certain high level, the learning improvement stops increasing no matter how much SDL time is spent, indicating that some other factors, such as learning strategies, might have influential effect on PBL when learner engagement is high enough; in year 2, the lower the learner engagement is involved, the smaller the influence of SDL time is on learning outcomes.

The Model of PBL Effectiveness in Engineering Design
3) The optimal amount of SDL time varies in different academic years. In year 1, the optimal SDL time is about 55-58%; in year 2, the optimal SDL time occurs at the two extremes, and the relative optimal SDL time is about 70%; in year 3 the optimal amount of SDL time is about 80%.

4) In year 1 and year 3, the optimal amount of SDL time is correlated with both the optimal design ability improvement and optimal transferable skill improvement. However, in year 2, the optimal amount of SDL time which is correlated with the optimal design ability improvement would be correlated with the lowest transferable skill improvement; likewise, the optimal amount of SDL time which is correlated with the optimal transferable skill improvement would roughly be correlated with the lowest design ability improvement. This result can explain to a certain extent the complexity of the optimal SDL time in year 2.

5) There are optimal individual SDL time and team-based SDL time respectively correlated with optimal learning outcomes, and they also vary in different academic years. The optimal individual SDL time is similar across academic years; however, the difference in the optimal team-based SDL time across academic years is great. In year 1, the optimal team-based SDL time is about 45%; in year 3 the optimal team-based SDL time is about 70%. Again complexity occurs in year 2, where the team-based SDL demonstrated a vibrating wavy-like trend. The regularity of the vibration is 20% and 15% in turn, and the relative optimal amounts of team-based learning in year 2 are 35% and 70%. The complexity in year 2 calls for more careful treatment in students’ teamwork.

6) The categorized learner engagement, namely, behavioral learner engagement, affective learner engagement and cognitive learner engagement, is positively correlated with the learning outcomes in PBL, that is, more categorized learner engagement would bring higher learning outcomes. In each academic year, the high learning outcome is correlated with a different pattern of the amount of categorized learner engagement from that of the medium & low learning outcomes; The extent of influence of each categorized learner engagement is different in different academic years, and comparing the three categorized learner engagement, the affective learner engagement has more influence on learning outcomes than the other two.
7.6.2 Team dynamics, Design problem, Lecture, Tutorial and PBL Effectiveness

Generally speaking, the team dynamics, design problem, lecture and tutorial have positive relation with PBL effectiveness, that is, more support of these parameters is correlated with higher learning outcome (with the exception of lecture in year 3 & 4 where more support of lecture might lead to lower learning outcomes).

To achieve the same learning outcome, more support of team dynamics is needed in year 2 than in year 1 and year 3 & 4. Such result corresponds with the complexity of team-based SDL time in year 2.

In the relation between tutorial and PBL effectiveness in year 3 & 4, a standstill in learning improvement occurs within the middle extent of tutorial support. This indicates that in year 3 & 4, when the support from tutorial is not great enough, further learning improvement is hard to be achieved. Similar standstill in learning improvement occurs in the relation between lecture and PBL effectiveness in year 2, indicating that in year 2 great enough support from lecture is needed to avoid students’ learning outcomes from stopping improving.

7.6.3 The Influence of Previous Engineering Experience on the Relation between SDL Time, Learner Engagement and PBL Effectiveness

The influence of previous engineering experience on the relation between SDL time and PBL effectiveness can be seen from two aspects:

First, the influence on the optimal SDL time. In year 1, the optimal amounts of SDL time for students with and without previous engineering experience are different. For students with previous engineering experience, the optimal SDL time is 35% and 85%; for students without previous engineering experience, the optimal SDL time is about 60%. Thus, the amount of the optimal SDL time needed by students with previous engineering experience is either greater or less than that needed by students without previous engineering experience. Students with previous engineering experience need less amount of SDL time to achieve optimal learning.
improvement because the prior knowledge they have learnt from their practical experience may help them better and quicker understand what needs to be learned; in addition, the practical experience can also help reduce the time for unnecessary or impractical mistakes. On the other hand, for some students with previous engineering experience, they may need less guidance from the teacher and prefer more SDL time to complete the design project by themselves on the basis of prior practical knowledge. Therefore, the students with previous engineering experience need either less or more SDL time than the students without previous engineering experience.

It should be noted that the optimal amount of SDL time for students without previous engineering experience, that is 60% SDL time, may bring the relatively low learning improvement for students with previous engineering experience. This might implicate that the same amount of guidance from the teacher fit for students without previous engineering experience would not be workable for students with previous engineering experience, and even have negative effect on their learning improvement.

In year 3 & 4, it can be found that the students with and without previous engineering experience have similar amount of optimal SDL time, about 75%. This indicated that the previous engineering experience does not have any influence on the amount of SDL time in the two groups of students. This might be because of the fact that the students in year 3 & 4 have already had a certain degree of self-directed learning ability accumulated from either previous learning experience or previous practical experience. Thus the previous engineering experience could not influence the amount of SDL time any more as it does in year 1.

Second, the influence on the learning improvement. It can be found that in year 1, the optimal PBL effectiveness achieved by students with previous engineering experience is higher than those of students without previous engineering experience. By contrast, in year 3, the optimal PBL effectiveness achieved by students with previous engineering experience is much lower than those of students without previous engineering experience.

Such conflicting results can also be found in the relation between learner engagement and
learning improvement where in year 1, when the same extent of learner engagement is made, the learning improvement achieved by students with previous engineering experience would be higher than that achieved by students without previous engineering experience; whereas in year 3 & 4, when the same extent of learner engagement is made, the learning improvement achieved by students without previous engineering experience would be higher than that achieved by students with previous engineering experience.

The different influence of previous engineering experience on the learning improvement between year 1 and year 3 & 4 can be explained from cognitive learning theories. According to Piaget’s schema theory, there are two parts of adaptation in learning process: assimilation and accommodation. The former refers to the process of taking in new information into the previous schema, and the latter refers to the process of changing or altering existing schemas in light of new information. Ausubel’s assimilation theory also emphasized the importance of what learners already know in that learning occurs through the new concepts into existing concept framework held by the learner.

For year 1 students with previous engineering experience, they have more practical knowledge about realistic design projects than those students without engineering students. That is to say, they would like to be more consciously taking in new information and fitting it with their existing concept framework. Thus, their previous engineering experience can help them to learn more or understand deeper than their counterparts without previous engineering experience, hence higher learning outcomes.

For year 3 & 4 students, the same advantage is also enjoyed by those students with previous engineering experience. However, it should be noted that in the UK, the previous engineering experience of year 3 & 4 students may be gained from their previous design project modules and/or practical placement work or Sandwich courses. Therefore, in year 3 & 4, this group of students has already had a certain extent of knowledge about design projects and need not learn it from scratch; whereas for the students without previous engineering experience, compared with the students with previous engineering experience, they have to learn more in order to
achieve the same level of learning outcomes, hence higher learning improvement.

7.7 CONCLUSIONS

In this chapter, an experiment was conducted based on the schematic model of PBL effectiveness with two key parameters of PBL taken into consideration – self-directed learning and learner engagement. Rigorous mathematical and statistical methods were applied in the experimental data analysis based on which a 3-D model of PBL effectiveness was built and the relation between SDL time (including the total SDL time, individual SDL time and team-based SDL time), learner engagement (including the total learner engagement and categorized learner engagement) and learning improvement (including the total learning improvement and categorized learning improvement) were determined. In addition, some other learning parameters in PBL, including team dynamics, design problem, lecture and tutorial were examined respectively and their relations with learning improvement were also identified. Finally, the influence of previous engineering experience on the relation between SDL time, learner engagement and learning improvement was also analyzed. Discussions and implications were made and all the findings can provide guidance for PBL practitioner in engineering design.
Chapter 8.

EFFECTS OF INDIVIDUAL DIFFERENCES ON PBL TEAM EFFECTIVENESS IN ENGINEERING DESIGN

8.1 PURPOSE OF THIS STUDY

In chapter seven, the relation between the two parameters of PBL, SDL and learner engagement, and the PBL effectiveness were explored, and a model of PBL effectiveness was built based on the findings in the experiment. In the model, the trends of PBL effectiveness were discovered and relative optimal PBL implementations were determined with the proper proportion of the two parameters of PBL - SDL time and learner engagement. In addition, the relation between other parameters (i.e. team dynamics, design problem, tutorial and lecture) and PBL effectiveness as well as the effect of the influencing factor (i.e. previous engineering experience) on this model were also studied.

It should be noted that the model of PBL effectiveness built in chapter seven was based on the aggregation of student SDL time and learner engagement (with method of moving average) and the average of corresponding learning improvement. In the course of aggregating and averaging, students’ individual differences involved in the learning process were inevitably overlooked.

There has been much research on individual differences in teamwork. However, the majority of relevant research was based on the static analysis, and studies which take the teamwork as a dynamic process is called for. The dynamic interaction of the individual differences in teamwork can be complex. Based on the model of PBL effectiveness in chapter seven, this chapter was aimed to study the dynamic interaction of PBL teamwork from the perspective of individual differences, which would be a supplement to the model of PBL effectiveness.

8.2 DEFINING INDIVIDUAL DIFFERENCES AND TEAM EFFECTIVENESS

8.2.1 Defining Individual Differences in this Study

In this study, the individual difference was defined at three levels, namely, 1) a priori individual differences; 2) team-based individual differences and 3) interaction-based individual differences.

1) A priori individual differences
This aspect of individual differences was based on the following four categories summarized from the research on individual differences in learning and studying (Johnson and Grabowski, 1993; Hartley, 1998; Cassidy, 2004):
a) Fundamental differences (e.g. culture, age, intelligence, sex, etc)

b) Cognitive styles / learning styles / learning strategies (e.g. convergent/divergent thinking; deep/surface learning approach; Kolb’s learning style, etc)

c) Personality and preferences (e.g. introversion/extraversion; motivation; interest, locus of control, etc)

d) Prior knowledge (e.g. Prior learning experience, prior academic achievement, etc)

This aspect of individual differences was termed as a priori in the sense that the principles of these individual differences are generally regarded as fixed or relatively fixed characteristics of individuals which tend to suggest likely effects. One feature of the individual differences in the above four categories is that much of the relevant research achievement was made on the basis of individual learning context rather than team-based learning context. How these individual differences may affect team learning effectiveness is relatively less studied.

2) Team-based individual differences
This aspect of individual differences was based on group characteristics related to team effectiveness in the teamwork process (Campion et al., 1993; Kozlowski and Ilgen, 2006; Mathieu et al., 2008). The general categories relevant with this study include:

a) Task significance for individuals (e.g. difficulty/challenge levels, relevance with personal goals, etc)

b) Individual commitment/contribution (e.g. Amount of project work)

c) Individual roles in the teamwork (e.g. leader or follower/supporter)

d) Individual learning from team mates

3) Interaction-based individual differences
This aspect of individual differences was based on the characteristics of interaction in team learning process. There are different categories/models of team learning interaction, for example, the Bales interaction analysis categories which include task-oriented category, process-oriented category and individual-focused category (Bales, 1950), Flanders’ interaction analysis categories (Amidon and Hough, 1967) which include the direct and indirect teacher and student talk, Webb’s model of peer interaction and learning in small groups which focuses on the levels of elaboration of and responses for help (Webb, 1989, 1992), and the recent method of analyzing group interaction in problem-based learning which focuses on elaborations and co-constructions as indicators of individual and group knowledge construction (Visschers-Pleijers et al., 2004). Among these Bales’ interaction analysis categories are widely recognized for small group learning and Flanders’ interaction analysis categories are suitable for teacher-student interaction process.
In project-based learning, there are two major interaction contexts for project teams: the tutorial context and the teamwork context. In the former, the interaction mainly happens between the teachers and individual team members; in the latter, the interaction occurs between team members. In this study, the interaction in both of these two contexts was studied.

**8.2.2 Defining Team Effectiveness in this Study**

In this study, team effectiveness was defined from two perspectives: one was from the external examiners’ perspective, that is, the teacher’s or professional’s assessment; the other was team members’ perspectives, that is, individuals’ satisfaction, commitment and viability (Kozlowski and Ilgen, 2006; Mathieu et al., 2008).

**8.3 RESEARCH METHODS**

This study was in the form of case studies based on teamwork observations and interviews. Teamwork observations were made in the context of the team-based tutorials and self-directed team meetings outside of class. The focus of teamwork observation was individual differences, particularly the interaction individual differences, in the teamwork process.

Semi-structured and in-depth interviews were conducted by the end of the design project modules. The focus of the interview was individual differences and team effectiveness from the perspective of individual team members. The interview was composed of three main aspects: 1) a priori individual differences, including reasons for choosing the degree programmes, future career goals, prior engineering experience, drive for learning, their preference for PBL; 2) team-based individual differences, including challenging/difficult part(s) of the design project; roles taken in the teamwork (leader or follower), teamwork distribution, individual contribution and time issues for team meetings; 3) perceptions of the teamwork effectiveness, including the usefulness of teamwork, learning of engineering design and knowledge application, and learning from team mates.

**8.4 DATA COLLECTION AND DATA ANALYSIS**

**8.4.1 Data Collection**

A case study was made with one first year mechanical engineering project team (totally six students). The selection was under the agreement of the students and with the support from their module lecturer.

The year 1 module lasted one semester, including a sugar machine design phase (week 1- week 7) and a period of subsequent hand-on work at workshops (week 8- week 12). An industry sponsored competition was held among project teams at the end of the module. The learning in
this module was team-based from beginning to the end, and the web-based peer assessment (WPA) was applied at the end of the module.

The way of team formation in year 1 was based on students’ prior engineering experience. The experienced students were asked to step up voluntarily and then other students chose to join him/her based on their own willingness.

The observations on the first year team lasted one semester in 2009. All the verbal interaction was audio taped. Information of the teamwork observations at tutorials and team meetings in year 1 was shown in Table 8.1:

<table>
<thead>
<tr>
<th>Categories</th>
<th>Number of observations</th>
<th>Time of observations</th>
<th>Length of observation</th>
<th>Participants (student A B C D E F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team tutorials</td>
<td>4</td>
<td>Week 3</td>
<td>27 minutes</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Week 4</td>
<td>12 minutes</td>
<td>Student E absent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Week 5</td>
<td>9 minutes</td>
<td>Student F absent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Week 6</td>
<td>10 minutes</td>
<td>Student B D E F in lab</td>
</tr>
<tr>
<td>Team meetings</td>
<td>5</td>
<td>Week 4 (twice)</td>
<td>1h 41m / 1h36m</td>
<td>Student E absent/ Student CDE absent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Week 6 (twice)</td>
<td>3hs /1h</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Week 7</td>
<td>2hs</td>
<td>Student E absent</td>
</tr>
</tbody>
</table>

By the end of the module, the students in the team under observation were asked to fill in a form about their allocation of time for the different learning activities in the course of PBL module. The time allocation form used in the interviews was the same as the one in the questionnaire in chapter seven. The purpose is to know the amount of SDL time spent by the team and to verify the relation between SDL time and PBL effectiveness found out in chapter seven.

After the completion of the design project module, semi-structured and in-depth interviews were conducted with each individual team members. Five students in this year 1 team participated in the interviews. Details of the participants in the interviews were shown in Table 8.2:
Table 8.2. Participant information in the interviews with year 1 team.

<table>
<thead>
<tr>
<th>Academic years</th>
<th>Interviewee</th>
<th>Length of the interview</th>
<th>Time of the interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>A</td>
<td>55 minutes</td>
<td>May 2009</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>53 minutes</td>
<td>June, 2009</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>42 minutes</td>
<td>May, 2009</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>47 minutes</td>
<td>June, 2009</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>36 minutes</td>
<td>May, 2009</td>
</tr>
</tbody>
</table>

8.4.2 Data Analysis

All the teamwork observations and student interviews were transcribed for data analysis. The effect of individual differences in the interaction at team tutorials were analyzed on the basis of two categories in the student-talk part of Flanders’ Interaction Analysis Categories: student talk-responses (i.e. talk by students in response to teacher) and student talk-initiation (i.e. talk by students which they initiate). The effect of individual differences in the interaction at team meetings were analyzed on the basis of Bales Interaction Process Analysis Categories: task-oriented category and social-emotional-oriented category. Thematic analysis was used to analyze the effect of individual differences found in the interview data. In addition, the prior academic scores of year 1 team and the final project assessment (obtained from module lecturers) were taken into consideration in the data analysis.

8.5 FINDINGS

8.5.1 The Relation between SDL Time of Year 1 Team and the Final Project Assessment

The allocation of time for the learning activities by individual team members in year 1 team was calculated and the average percentage of SDL time spent by year 1 team in the design project module was 55%, as shown in Table 8.3:

Table 8.3. Percentages of time allocation in the learning activities of the year 1 team under observation.

<table>
<thead>
<tr>
<th>Learning activities/ Individual time allocation</th>
<th>a</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>e</th>
<th>f</th>
<th>Average SDL (c+d+e+f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual time allocation</td>
<td>Lecture</td>
<td>Team tutorial</td>
<td>Individual tutorial</td>
<td>Team SDL</td>
<td>Private SDL</td>
<td>Informal peer interaction</td>
<td></td>
</tr>
<tr>
<td>Student A</td>
<td>10%</td>
<td>25%</td>
<td>5%</td>
<td>50%</td>
<td>10%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Student B</td>
<td>15%</td>
<td>20%</td>
<td>0%</td>
<td>40%</td>
<td>25%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Student C</td>
<td>30%</td>
<td>10%</td>
<td>0%</td>
<td>30%</td>
<td>20%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Student D</td>
<td>30%</td>
<td>10%</td>
<td>10%</td>
<td>30%</td>
<td>10%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Student E</td>
<td>15%</td>
<td>60%</td>
<td>0%</td>
<td>20%</td>
<td>5%</td>
<td>0%</td>
<td>55%</td>
</tr>
</tbody>
</table>

Then the final team project assessment was checked. The final project assessment was made by lecturers and company professionals. It was found that the year 1 team observed in this study was graded as the top six teams out of the total twenty four teams in year 1 and entered the final
company-sponsored competition. That is to say. The year 1 team achieved an above average learning outcome. This result verified the PBL effectiveness model in chapter seven that the percentage of SDL time at about 55% in year 1 is likely to bring the optimal learning outcome.

8.5.2 Effects of Interaction-based Individual Differences on Team Effectiveness

8.5.2.1 Effects of Individual Differences in the Interaction at Team Tutorials

The individual differences in the interaction at the year 1 team tutorials were studied from two main categories: student talk-responses and student talk-initiation, based on Flanders’ Interaction Analysis Categories. In the category of student talk-responses, students responded to the talk initiated by the teacher, thus in this category, the teacher takes control in the interaction; in the category of student talk-initiation, students initiated the talk and take control in the interaction.

Under each category, there were sub-categories concerning the detailed features. Tallies were used to count the frequency of each team member’s talk in these sub-categories. Detailed information was shown in Table 8.4:
In tutorial 1 which was the first time the teacher assessed the team’s initial design ideas and drawings, it can be seen that student A was the most active student in both the talk-responses and talk-initiation categories. The main role he played was to answer the teacher’s questions about the team’s design ideas and drawings. He was also the only student in the team who asked questions to the teacher.

Student E was found active in the talk to support student A. This was because the initial drawings of their design was mainly done by her, and she supported student A in his clarification where necessary.

Student C was found active in responding with the teacher with agreement. He was also the one who made some humorous talk during the tutorial, which made the assessment atmosphere relaxed. However, his function of clarifying the design work to the teacher was limited.

\*The Effects of Individual Differences on PBL Team Effectiveness in Engineering Design*
Likewise, the other students, including student B, D and F only made short and occasional clarification to the teacher.

Thus, in tutorial 1, student A took the most responsibility for clarifying the team’s work to the teacher, with student E as the main team supporter. Student C did some non-clarification talk which activated the team dynamics. The other three students’ talk was quite limited. The individuals’ roles in the interaction described above could be shown in Figure 8.1. The breadth of the arrows indicated the responsibility taken by individuals in the interaction with the teacher.

![Figure 8.1. Individuals’ roles in the interaction in team tutorial 1 in year 1.](image)

In team tutorial 2 and 3, the teacher mainly checked the team design progress and provided support and advice concerning the feasibility of their design. It can be found that generally the student talk-responses decreased and student talk-initiation increased. The discussion with team mates was increased in these two tutorials because when the teacher checked their design progress, the team was still in the middle of their discussion.

From Table 8.7, it can be found that student A still took the active role by answering teacher’s questions, made initiative clarification where necessary and asked teacher questions. Unlike in tutorial 1, student B’s and E’s initiative clarification began to increase, and student B also asked teacher questions in tutorial 3. The other students, student C, D and E make similar talk as before, with student C and E relatively active and student D being quiet.

Thus, it can be seen that in these subsequent two tutorials, more team members had talk-initiation interaction with the teacher and clarifying their ideas, and the responsibility of the team members gradually became equal, with the exception of student D. The individuals’ roles in the interaction described above could be shown in Figure 8.2 and Figure 8.3:

The Effects of Individual Differences on PBL Team Effectiveness in Engineering Design
In tutorial 4, student A and C came to ask questions to the teacher, with the others in the lab doing CAD. From Table 8.7 it can be seen that between the two students, student A was more active in asking questions and answering the teacher’s questions than student C. The individuals’ roles in this tutorial could be shown in Figure 8.4:
In summary, in the interaction at team tutorials in this year 1 team, student A was different from other team members in that he remained an active role at all the four tutorials and had the most of both student talk-responses and student talk-initiation interaction with the teacher. His active role had positive effect on the teamwork in that the teacher could understand their design ideas clearly and gave effective support and advice to their design project. Most other students generally could have an active role at the team tutorials, making mainly student talk-initiation interaction with the teacher. The effect they had on the teamwork was that they could provide various ideas from their own perspectives to be assessed by the teacher and thus helped the development of their design project. Student D was the most inactive one in the team who made only occasional interaction with the teacher and other students. Thus, student D’s contribution at the team tutorials was limited.

8.5.2.2 Effects of Individual Differences in the Interaction at Team Meetings

The analysis of the year 1 team meetings was based on Bales Interaction Process Analysis and the interaction features fell into two general categories: task-oriented category and social-emotional-oriented category. In the task-oriented category, there were two general sub-categories: giving information and seeking information. The former included 1) generating ideas; 2) evaluating ideas (including agreeing and critical thinking)); 3) suggesting, including suggesting the use of references and the steps of measures); 4) summarizing ideas; 5) deciding on ideas; 6) providing general information; the latter included 1) seeking opinions; 2) seeking clarification. In the social-emotional-oriented category, there were also two general sub-categories: positive reinforcement and negative reinforcement. The former included encouraging (i.e. motivate to participate), harmonizing (i.e. reduce conflicts, etc), and tension reducing (make humorous talk, etc.); the latter included blocking (i.e. state difficulty to block progress), dominating (i.e. have one’s own agenda and stubborn to change ideas) and distancing (i.e. distance oneself from others).

Based on these categories, the individual differences in the interaction at the year 1 team meetings were analyzed. Particular focus was put on the interaction at the first team meeting under observation because of two reasons: first, the team’s design project framework mainly took form in this team meeting; second, most team members turned out in this team meeting and thus it could reflect most individuals’ interaction features.

It was found that the first team meeting could be divided into three phases according to the topics in the team meeting interaction: phase one was focused on student A’s design ideas; phase two was focused on student C’s design ideas; phase three was focused on the settlement of problems in student C’s design ideas. The interaction features of the individuals in these three phases were shown in Table 8.5, Table 8.67 and Table 8.7 below respectively (The tallies

The Effects of Individual Differences on PBL Team Effectiveness in Engineering Design
represented the frequency of the interaction made by individuals, and the numbers in bracket represented the actual statements individuals made in the interaction. The amount of the tallies corresponded to the amount of the individuals’ statements.

(A) Individual differences in team meeting interaction - Phase one

Table 8.5 Individual differences in the interaction at the team meeting 1 in year 1 team – Phase one.

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<th>Categories</th>
<th>Sub-categories</th>
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</table>

In phase one, the focus was mainly on student A’s design ideas. From Table 8.5 it could be seen that in the category of generating ideas, student A and student C made obviously more amount
of statements than the other three, with student F making no statement in this category. This indicated that in phase 1, student A and C provided more design ideas and more creative than the others. From the actual statements, as shown in the script below, it was found that student C’s design idea generation was stimulated by his team mates (student B) and was based on others’ design ideas and concepts stored in his prior knowledge. This indicated that in phase 1, student C’s ideas were not original yet, but he was good at applying others’ ideas and concepts to the design project.

In the category of evaluating ideas, it could be seen that student A, B and F made more critical statements. From the actual statements, as shown in the script below, it was found that student B and F played the main role in identifying problems in student A’s design ideas. The difference between them was that student B supported student A’s design ideas to some extent, whereas student F did not approve it and suggested to try other ways. Their attitudes to student A’s design ideas could explain why student B could manage to generate a few design ideas whereas student F did not make any effort to generate ideas.

---

[42] B: Is there any crank design because I’m sure there is that honestly would have a whole period, like a leg, as you said. I think it would be, what’s the name that some will develop.

[43] B: Really you need to get some thought. We’ll find an idea, won’t we?

[46] C: Someone … they used the mechanism …

[47] F: Really?

[48] C: Yea. What about that? I mean as long as you can use sth that gets the mechanism. It’s going to spin like inside that.

[49] B: Yea. I mean we’ve thought about doing with it.

[50] C: Yea, we need the circuit because you got that on the thing and change it.

[51] F: You’ve got a place. …

[86] B: Well, it can really change everything.

[87] C: Yea, you know the concept, well, like the P… idea. If we have one, then you could do it, like turned as it went it, and going in it, returned under way down and under way up.
Different from student A, B and F, student C made only a little critical evaluation but the most agreeing evaluation. In addition, he also made some statements in the category of seeking information. From the actual statements, as shown in the script below, it was found that student C managed to understand the whole design framework and the problems of it by using the agreeing evaluation and seeking information before he started to provide his ideas.

Like student C, student A was also characteristic of seeking information. However, the purpose of his questions was mainly to stimulate team members and collect the team’s opinions to settle problems.
Different from student A and C who tended to seek information and generate design ideas, the significant individual feature in student B and student F was that they tended to make more principle-oriented summaries and decisions and holistic suggestions on steps of measures, as shown in the script below:

At the end of phase one, the problems in student A’s design framework could not be settled, then student C came up with a new idea which changed their basic design framework, and the interaction focus entered phase two.

(B) Individual differences in team meeting interaction - Phase two
### Table 8.6 Individual differences in the interaction at the team meeting 1 in year 1 team — Phase two.

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<th>Categories</th>
<th>Sub-categories</th>
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<th>C</th>
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<td>Task-oriented</td>
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In phase two, the interaction was mainly focused on the design ideas generated by student C. It could be found that in the category of generating ideas, most ideas were generated by student C, and a few ideas were generating by student B. An interesting point was that in the very beginning student C’s design ideas were again stimulated by student B to some extent, as shown in the following script:
Student C’s ideas got the agreeing evaluation from student B and student F, who helped develop his ideas. However, his ideas also had problems which needed to be settled, thus some critical evaluation was made as well by student A, B and F. The main criticism was on the stirring issue.

In the category of encouraging, it can be found that despite of the existence of problems in student C’s design ideas, most team members showed their appreciation of his ideas, which helped the positive reinforcement in their design process, as shown in the following script.
With the recognition of student C’s design framework by the team, the interaction focus transferred to the settlement of its problems, including the discussion on size stuff, thus their design process entered into phase three.

(C) Individual differences in team meeting interaction - Phase three

Table 8.7 Individual differences in the interaction at the team meeting 1 in year 1 team – Phase three.

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The Effects of Individual Differences on PBL Team Effectiveness in Engineering Design
The focus of phase three was settling the problems in student C’s design ideas put forward in phase two. From Table 8.7 it can be found that in the category of generating ideas, student A and C generated quite many design ideas; student F also made some idea generation, but less than student A and C. By contrast, student B and D made little contribution in the idea generation. Therefore, in phase three, student A and C were the most active in idea generation and thus most creative compared with other team members.

In the category of idea evaluation, student A, B and F made roughly equal amount of agreeing evaluation and critical evaluation respectively; student C made similar amount of agreeing evaluation as student A, B and F, yet much less critical evaluation than they did. In the whole evaluation category, student D made very little contribution.

Another feature in student A and C which was different from others was that the two students tended to ask for concrete opinions or clarification. This helped them to seek more information from their team mates as sources for their design thinking, as shown in the script below.

(D) Summary of the individual differences in the interaction at team meeting 1
From the findings of the individual differences in the three phases of the interaction at team meeting 1 under observation, a summary can be made as follows:

1) Student A was very active in idea generating, which indicated his good creative ability in the teamwork; besides, he also made a good amount of critical evaluation at design ideas throughout the three phases, which showed his good critical thinking ability. Moreover, he was good at seeking information from his team mates, which helped to motivate the team members’ thinking activities.

2) Student C was very active in idea generating, which indicated his good creative ability in the teamwork. And he was good at making agreeing evaluation at others’ ideas and opinions, which could stimulate his idea generation. However, he was not good at critical evaluation,
which showed his limitation of critical thinking ability. Like student A, student C was also good at seeking information from team mates, which he mainly used as sources of his design thinking development.

3) Student B and F showed much similarity in the team work in that both of them made a good amount of critical evaluation throughout the three phases, which indicated that they had good critical thinking ability. In addition, both of them were good at making principle-oriented summaries and decisions and holistic suggestions, and some points they emphasized were abided by throughout the team design process. On the other hand, these two students did not make much idea generation, which indicated their limitation of creative thinking ability in design.

4) Student D was quiet in the team interaction. He made a little effort in the idea generation and evaluation, yet his interaction was very limited.

(E) Effects of individual differences in the interaction at team meetings on the team effectiveness

It can be seen that the individual differences in the interaction at the team meetings under observation generally had positive effects on the team effectiveness.

First, in the aspect of design idea generation, there were two students good at creative thinking in this team (student A and student C), whose contribution improved the creativity of their team design project.

Second, in the aspect of design idea evaluation, there were three students good at critical thinking in this team (student A, B and F), whose contribution improved the quality of their team design project.

Third, in the aspect of summarizing, decision-making and suggesting, there were two students good at making principle-oriented summarization and decision, and holistic suggestion (student B and F), whose contribution improved the teamwork effectiveness by guiding the discussion in the proper direction.

Forth, in the aspect of information-seeking, there were two students good at seeking opinions and clarification from their team mates (student A and C). Student A’s way of seeking information helped motivated the whole team thinking, and student C’s way of seeking information helped his own design idea generation, both of which had positive effect on the teamwork effectiveness.
The negative effect of the individual differences in the interaction at team meetings was there was one student in this team who did relatively little interaction with others (student D). Thus his contribution at the team meetings was limited, which potentially decreased the effectiveness of the teamwork by lacking another involved mind.

8.5.3 Effects of Team-based Individual Differences on Team Effectiveness

8.5.3.1 Roles in the Team

The individual differences in the roles in the year 1 team were studied from two perspectives: team leaders and team supporters. In this team, student A played the role of leader, and others played the role of supporters.

The leader role of student A in this team was reflected in two aspects: a) the leader role in tasks; b) the leader role in team organization.

The leader role of student A in tasks was paramount particularly in the design phase of the team project, during which he helped guide the team design project to the practical and realistic direction.

Student A: “I would say I was the person who thought about it practically. I think I can realize what is likely to be made of. Some people come up with ideas that can’t be made or an idea that is physically too big or over-complex, so I think I was sort of the person who said that, ‘look, that can’t be made.’.”

Student B: “In our team we may have slight sway towards student A. He is quite experienced in engineering as he’s previously done some designing and such things, so he would talk about designing sth, he would have more say on what has to be made. He is in a slight leading role in designing in that sense.”

Student D: “He (student A) did quite a lot in the design phase, I thought. He collected our ideas, so I think student A took like the leadership role.”

In the team organization aspect, student A took charge of collecting the team emails, and he was the one who attended every team meeting throughout the design project module (the other one was student B). He was also the most active members in the interaction both with the module lecturer at team tutorials and with his team mates at team meetings.

Student C: “He organized the group well, support[ing] a lot of time we had.”

It was found that previous industrial experience was one of the reasons for students to take the leadership role in this team. Student A had the previous realistic engineering experience which was the basis for him to take the leading role in the teamwork:

The Effects of Individual Differences on PBL Team Effectiveness in Engineering Design
Student A: “I put up my hand when he [the lecturer] asked who’s got the workshop experience, so I went to the front, and from then when Peter [the lecturer] said, you know, that everyone else can go and pick who they would like to work with. When people came to me to work with, probably they know me, you know, we worked well together in the past, I think by that, all was chosen sort of a leader.” “I mean obviously I was the person who stood up to the front and I was the team leader as such, you know. As I said, because I had a bit of practical experience, it is fair by saying that…. in general, I would say that I was the person who grouped them together, and then let the team learn more.”

For others, most of them thought they could not take the leadership role in this project because they did not have enough engineering knowledge to do so, and they expressed their willingness to take the leader role in future if they have enough relevant knowledge.

Student B: “I will be happy to be more a leader, but this project that wouldn’t be right because I had not previously learnt enough in engineering to be known really to take charge….But you know, in future, when everyone was on part, [when] they know less knowledge than you, I would be happy to step up and take up more control.”

Student C: “Yea. I would, I’ll quite love to. But this time I think I didn’t have much experience working with it but in the future do it hopefully the leadership role.”

Besides previous industrial experience, personality was another reason for students to take the leadership role. It can be found that student A had the initiative to take the role of leader in teamwork and he thought he was the type of person being active in teamwork.

Student A: “I always saw myself as leader role. I’m not somebody to sit back and just not really show much, [or] just follow whatever else does because if [so] you can never do something to improve your project and to improve group work in all.” “I was promoted to a leadership or something. I think that’s just the type of person you are.”

By comparison, student D tended to remain quiet in the teamwork:

Student D: “I just tend to stay quiet, just generally, and in group I wasn’t active as you observed. It’s the way I’m in a group. I like trying to get a few good ideas. That’s really what I like - I just put my ideas there and see every one got to work.”

Unwillingness to take more responsibility for the team was another reason for some students not to take the leadership role in the teamwork, like student B in this team:

Student B: “I don’t mind that (being a team leader) too much, but sometimes the question is you don’t want to have the huge responsibility for the people…. Sometimes it’s quite nice to be just one of the people who is, you know, when someone else is in charge at the meeting, you just sit back.” “I enjoyed having quite equal and just have given my input but without having to do it too much.”
In summary, in this year 1 team, the team leader had the previous engineering experience and the initiative and personality as the basis for him to take the leading role in tasks and organization; the other team members took the role as supporters either because of the lack of enough engineering experience or personality or because of personality or responsibility. Generally speaking, the leadership in this team was effective and had positive effect on the whole team effectiveness, including the practical guidance for the design project and the team organization.

8.5.3.2 Individual Contribution
Generally speaking, there was fair individual contribution in the teamwork in this year 1 team, and each team members could spare their effort and undertook a fair share of work.

Student B: “I think in our group there was fair call and working and quite good personality. Everyone was very able in the group.”

Student D: “I think everyone did like quite an equal share of them. I can’t think one person who didn’t.”

It was found that the individual differences in the team contribution were relevant with the individuals’ subject strengths to some extent. The biggest difference in team members was the practical strength in student A and the theoretical strength, such as maths and physics, in other team members. Such different strengths had positive effect on the teamwork in that the ideas from different perspectives could lead to better solutions.

Student A: “When we developed ideas, it is good that we can have different backgrounds because if we’ve had completely different ideas, and because we’ve had completely different ideas, I think we found [the] solution that was a better idea.”

Another feature of the individual contribution in this team was that the team members tended to make more effort in the share of teamwork which they think they were good at, for example, student D’s CAD drawings, student E’s design sketches and making manufacture at workshop as well as student A’s contribution in the design phase.

Student D: “He (student A) did quite a lot in the design phase…”

Student D: “I’ve studied CAD at college, and then we did it again at foundation year, and we had a module this year at Peter’s design, so I was quite learnt with the software.” “I did a slightly quite a lot of CAD [in this project].”

Student D: “…like the initial sketches from student E. She is quite good at initial drawings….” “She was quiet, and she’s got a lot of skills; she is quite strong on map, like sketch phase of the project, like she did a lot like making manufacture herself.”
In summary, the individual differences in the individual contribution to the teamwork were related with the individuals’ subject strengths to some extent. The differences in subject strengths in the teamwork had positive effect on the teamwork in that the combination of different perspectives could lead to better design solutions; in addition, the differences in subject strengths also led to more effort on the corresponding share of teamwork.

8.5.3.3 Learning from Team Mates

The individual differences in learning from team mates were studies in two aspects: a) learning from team mates based on the help got from others; b) learning from others based on personal perception of learning improvement.

Most of team members learnt from their team mates based on the help they got from others. A case in point was student C who benefited much from his team mates’ help and learnt new things accordingly.

Student C: “I think it helps quite a lot because if people know sth. that you don’t, like you can’t find it in the textbook, then you learn sth. new.” “From student A I did on the machines, and then, student D on the CADs, on the software and computer issues, sort of that. [They] showed me to use it and [I] learnt new things…”

For student A as the team leader, it seemed that his learning from team mates was limited in that his perception of learning was confined to the learning only in the design phase.

Student A: “I learn from different ideas, different concepts, which come from the initial idea. That is sth. I haven’t thought of, some mechanisms, some ideas. …I did learn some different ideas from other people, things like the way they think. Yea, I think I learnt these things in the early stages.”

For student B, he admitted that the help from others was useful for him, but he could not give any definite information as to what he exactly learnt from other team mates.

Student B: “There is someone now to step to help you out, which is useful. And also just help the team with what I want contributing.”

Different from other team members, student D learnt from his team mates mainly based on his own observation at the team mates’ strengths in the teamwork and he learnt them out of his initiative to make personal learning improvement:

Student D: “I think I learnt a lot from student A from his leadership skills, some of the practical drawing, like the initial sketches from student E. …So I think everyone had individual skills you could learn from.” “It’s very useful. It’s sth. I’m not very good at, so it’s sth that I can learn from.”

The Effects of Individual Differences on PBL Team Effectiveness in Engineering Design
In summary, the individual differences in the learning from team mates in this team were in two aspects: learning from the help got from others and learning from others’ strengths out of the initiative for personal learning improvement. It can be found that the former way of learning is relatively passive, however, it reflected good team dynamics and thus had positive effect on the team effectiveness; the latter way of learning is more active and reflective which can help develop personal learning improvement.

8.5.3.4 Challenging Aspects of the Team Design Project

The individual differences in the challenging aspects of the team design project in this year 1 team were found in two aspects: one was time management; the other was teamwork.

Both student A and B found that the design project was time-consuming which took away the time for studying other subjects. Therefore, good time management was challenging to them.

Student A: “If it is any more challenging, it takes time away other things, I mean other subjects and lectures and stuff. There is a lot of work you’ve got to do to get a final idea. [For example,] the college workshop last week, it took a lot of time like that.”

Student B: “[The challenging thing is] Just have design done in time, that sort of thing… I think just managing good time to do it really.”

For student B, D and E, They found the way of teamwork was challenging to them, especially in terms of communication:

Student B: “It’s challenging, [for example,] to work as a group; learn to work as one when you didn’t [have] design ideas, not having constant debating [on] different things.” “I’m not used to the socializing with people, because I just like to do in my own way.”

Student D: “It was very challenging because there is sth that I’m still not good at, just like the communication and teamwork phase.” “I just tend to stay quiet, just generally; and in group I wasn’t active as you observed. It’s the way I’m in a group.”

Towards to challenging aspect of design projects, individuals’ attitudes to them could be different. A comparison can be made between student B and student D, who took different attitudes towards the teamwork which they thought to be challenging:

Student B: “I think it takes more for me to work in a group than on my own …[When] you are working in a group and you have to look up what others are doing. It adds an extra dimension. I’m not huge fond of it.”

Student D: “I prefer the teamwork style as there is sth. in there that I need to improve on. I think I can get more from that style of learning.”
Thus, it can be seen that the challenging aspects in the design projects could have either positive or negative effect on the teamwork, depending on the individuals’ understanding of the value of the design project.

8.5.4 Effects of A priori Individual Differences on Team Effectiveness

8.5.4.1 Prior Learning Experience

In this study, the individual differences in prior learning experience in year 1 team were studied in three aspects: previous academic average marks, subject strengths and previous engineering experience.

1) Previous average academic marks

From the academic documents provided by the lecturer in this year 1 design project module, the individual differences in previous average academic marks of the six students in this year 1 team could be divided into two groups: (a) above average group, including student A, B, D and F whose average academic marks were above 65; (b) below average group, including student C and E whose average academic marks were below 60. Detailed information was shown in Table 8.8:

<table>
<thead>
<tr>
<th>Groups</th>
<th>Students</th>
<th>Previous Academic Average Mark</th>
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</thead>
<tbody>
<tr>
<td>Above average</td>
<td>Student A</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>Student D</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>Student B</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>Student F</td>
<td>65</td>
</tr>
<tr>
<td>Below average</td>
<td>Student C</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>Student E</td>
<td>56</td>
</tr>
</tbody>
</table>

It was found that the differences in previous academic average marks did not affect individuals’ effort on their share of teamwork. In this team, every one undertook a fair share of teamwork and thus made a fair amount of individual contribution. The individuals’ effort was appreciated by their team mates, which led to the satisfaction with the team dynamics.

Student A: “Everyone pulled the way, everyone did work hard.”

Student B: “I think in our group there was fair call and working and quite good personality. Everyone was very able in the group.” “I think it went really well. I was really pleased with the group.”

Student C: “I think we went quite well. If somebody has something to say, everyone would listen and take our point into consideration, and then when it came to the building, I think we all afford a fair share, so I think we’ve done quite well....”
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Student D: “I think everyone did like quite an equal share of them. I can’t think one person who didn’t.” “I think as a whole the group worked pretty well, I mean our project. The team remained quite well.”

It can be seen that in students’ comments on their teamwork the most frequent words occurred were fair or equal share of work. Therefore, the fairness in the share of teamwork, that is, the team members’ sufficient effort on the teamwork, could influence individuals’ satisfaction with the team dynamics, whether the team members are above average students or below average students.

2) Subject strengths.

It was found that individual differences in subject strengths could have some effect on team members’ choice of and effort on the share of teamwork, which further had effect on individuals’ learning from the team mates and potentially helped develop the good team dynamics.

The individuals’ subject strengths could be reflected to a certain extent in their individual subject marks. The following Table 8.9 showed the subject strengths of the individuals in the team in this study. It could be seen that student A, C, D and E were good at Drawing and CAD, student A, B D and F were good at Mathematics, and student F alone was good at Mechanics.

<table>
<thead>
<tr>
<th>Students</th>
<th>Subject strengths</th>
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</thead>
<tbody>
<tr>
<td>Student A</td>
<td>Drawing &amp; CAD (A)</td>
</tr>
<tr>
<td>Student B</td>
<td>/</td>
</tr>
<tr>
<td>Student C</td>
<td>Drawing &amp; CAD (A)</td>
</tr>
<tr>
<td>Student D</td>
<td>Drawing &amp; CAD (A)</td>
</tr>
<tr>
<td>Student E</td>
<td>Drawing &amp; CAD (A)</td>
</tr>
<tr>
<td>Student F</td>
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</table>

In this team the teamwork was allocated in a casual way on the basis of individual’s voluntary choice, as student E described:

Student E: “It was more like ‘you do this, you do that. Well this needs to be done, could you do that? Ok, you do that’, so it was quite casual sort of thing.”

The casual way of allocating teamwork provided room for individual team members to choose the share of work they were good at or did sufficient amount of teamwork which they were good at. For example, student E undertook the initial design sketches because she was good at it; student D did much of the CAD and software work in this aspect because he was experienced in it, and their subject strengths were the sources possibly to be learned by other team mates.
Student D: “I think I learnt …some of the practical drawing, like the initial sketches from student E. She is quite good at initial drawings. It is that skills that I tried to learn from them.”

Student D: “I’ve studied CAD at college, and then we did it again at foundation year, and we had a module this year at Peter’s design, so I was quite learnt with the software.” “I did a slightly quite a lot of CAD [in this project].”

Student C: “I learned from student D on the CADs, on the software and computer issues, sort of that.” “I did some drawing in CAD, that’s my fair share.”

Some of the strength could not be reflected in the academic marks, such as the workshop skills. Student A in this team had previous workshop experience, thus he had more machinery knowledge which other team members could learn from:

Student C: “Alex has done a lot of machinery stuff and he knew more about it, and he showed us how to use and then carry on again”.

Thus it can be seen that the individual differences in subject strengths could influence individuals’ choice of and effort on their share of teamwork, which could provide opportunities for other team mates to learn from, and could help develop the good team dynamics.

3) Previous engineering experience

In this study, the individual differences in previous engineering experience on team effectiveness was studied from two perspectives: one is previous realistic engineering experience, that is, students with previous realistic engineering experience, on the teamwork; the other is non previous realistic engineering experience, that is, students without previous realistic engineering experience, on the teamwork. Because the previous realistic engineering experience and non previous realistic engineering experience were like the two sides of the same coin, they would be discussed together.

In this year 1 team, it was found that previous realistic engineering experience had positive effect on the team effectiveness in that it helped guide the teamwork to the practical direction, while non previous realistic engineering experience tended to lead the teamwork to being more theoretical and unrealistic. The guidance effect of previous realistic engineering experience was paramount in the design phase.

In this year 1 team, as a result of the way of team formation, only student A had realistic engineering design experience; other team members had more or less engineering project experience mainly gained from the school or college education. Accordingly, in this team, student A was more practical-minded in design, whereas others, especially those who had little
engineering project experience before, such as student B, tended to be more theoretical-minded. It was found that the ideas between the two types of students would conflict in the team discussion, in which the previous realistic engineering experience of student A would help guide the development of the team design in the practical direction:

Student A: “Some ideas, theoretically it’s a good idea, but look from the side of practical background, you know, it can’t be made, or that’s hard to be made.”

Student B: “Student A knew more about it than me. I think I was one of the people who had more challenged some of his ideas, but at the end of the day, I knew he did have more knowledge than me.”

On the other hand, the previous realistic engineering experience also affected individuals’ understanding of the value of PBL. For example, student A with previous realistic engineering experience could appreciate the value of PBL in terms of real life skills, especially the benefits of group work in the idea development, whereas the team members without previous realistic engineering experience generally only emphasized the learning of technical aspects, such as student C and E.

Student A: “I think this project is the best to teach you the real life skills…. They teach work in the group, developing ideas, real engineering as in what you will do in the real life.” “It is good that we can have different backgrounds, because we’ve had completely different ideas, I think we found a solution that was a better idea.”

Student C: “I think you learn more doing in that way because you have to do it, you have to learn, [have to] remember how to use the machine, rather than just being told that.”

Student E: “With this [project] because we are going to the details ever again and again during the whole process, I think that’s sth I can remember.”

In addition, in contrast with student A’s appreciation of the real life skills in design project and the value of group work, student B who had little previous engineering group project experience held a negative attitude to the way of group work and the design project because they conflicted with his preferred way of learning and understanding of learning.

Student B: “I’m not used to the socializing with people, because I just like to do in my own way.” “I think it takes more for me to work in a group than on my own …[When] you are working in a group and you have to look up what others are doing. It adds an extra dimension. I’m not huge fond of it.” “In rough design, you can design it not so well, incident work so much…. It’s not as directed so it’s hard to know what is right or wrong.”

Because of the negative attitude to the group work and the design project, student B was the only one in the team who was just happy to do his own share of work and was not willing to undertake more share of teamwork.
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Student B: “In a group where everyone’s pretty cool I would be happy to be with my share. …I was happy just to do my own fair share, but also know that, you know, if I did less, I probably get slightly worse mark because we assess each other.”

It should be noted that the effect of non previous realistic engineering experience is not absolute. Sufficient previous engineering projects could also have positive effect on students in the teamwork. A case in point was student D. It was found that student D did quite a lot of group projects at college, and like student A, he was also aware of the value of PBL in terms of the group work.

Student D: “I think it’s a better way of learning rather than the traditional like just lectures and teachers because realistically if you go on with a job in engineering, you are not going to do lectures or doing exams, you are going to be doing, like group things, so it’s more like applicable in the career of engineering.”

Furthermore, like student B, student D was not good at communicating in the teamwork. But different from student B who had the negative attitude to PBL, student D had a positive attitude to PBL and was aware that his weakness needed to be improved. It was found that student D spared quite a lot of effort in the teamwork.

Student D: “I just tend to stay quiet, just generally; and in group I wasn’t active as you observed. It’s the way I’m in a group.” “I prefer the teamwork style as there is sth. in there that I need to improve on. I think I can get more from that style of learning.”

Student A: “Student D seems quiet but he does a lot of work you don’t realize, he is happy to do work. He is quiet. He doesn’t say…He is quite a lot more minded than I am.”

In summary, in the year 1 team, previous realistic engineering experience had a positive role in the teamwork by leading the design project to the practical direction whereas non previous realistic engineering experience would limit students to be theoretical-minded in design. Previous realistic engineering experience as well as sufficient previous engineering group projects could play a positive role for students to better understand the value of PBL, especially the value of team work, whereas non previous realistic engineering experience tended to confine students’ understanding of PBL to the knowledge aspect, and could cause those students who were used to the traditional way of learning and understanding to form the negative attitude toward design projects and teamwork.

8.5.4.2 Motivation

The individual differences in motivation in learning in this year 1 team was studied from three perspectives: 1) reasons for choosing the engineering degree programme; 2) future career goals; 3) drive for learning in this PBL module.
1) Reasons for choosing engineering degree programme

The reasons for choosing engineering degree programme in this year 1 team fell into three categories: a) interest in engineering; b) subject strengths; c) requirement of sponsorship.

Student A and D belonged to the first category. Both of them showed their interest in mechanical engineering, and the interest took hold in their previous engineering experience. For student A, his interest benefited from his family background which could provide him with some car making opportunities; for student D, his interest resulted from his mechanical engineering experience at college.

Student A: “I’ve got a bit practical background: I helped build a race car and things sort of that, the track things… In my own town as well, we tracked through the year. We got specialized car to drive and track. I mean it’s Dad himself providing it, probably made that.” “I suppose in my life until now, I’ve been involved in engineering things, be involved in practical things, you know, worked with cars and things. It was just interesting really.”

Student D: “It was during college that I decided I wanted to study mechanical engineering; I did the national employment in mechanical engineering at college as well, so I did quite like that experience and a lot of expectations in the university to study this. I really liked it in the college, so I followed down to study it.”

Unlike student A and D, student B and C did not have much engineering project experience, so they had vague understanding of realistic mechanical engineering. They chose the mechanical engineering degree programme mainly because they thought they were good at it.

Student B: “I find my strengths physics and maths, so I went for a degree which combines the two. It just looks like sth interesting.”

Student C: “Why mechanical? Because when we were doing A-level maths, mechanics was the thing I found the easiest among them. It’s just count of words, so I just get a go to mechanical.”

Although both student B and C chose the degree programme based on their subject strengths, their underlying motivation was different in that student B chose the degree programme according to his own willingness whereas student C’s choice was constrained by his sponsorship which only allowed him to do the engineering degrees.

Student C: “I went to a college near here, and it’s sponsored by a military, so we were only allowed to do engineering degrees. So I chose mechanical.”

Like student C, student B also had a military sponsorship. However, differences can be found between them in that student B liked the mechanical engineering experience at college very
much, which made him decide to study it at university, whereas student C changed his interest during the time of college and did not like engineering any more at university.

Student D: “It was during college, I decided I wanted it, to study mechanical engineering, and have a career in the military.” “…I really liked it in the college, so I followed down to study it.”

Student C: “I chose when I was sixteen, and between then and now there’s been three years, so I changed my mind about quite a few things…. [If not constraint by the sponsorship], I wouldn’t be doing engineering. [My interest is] sport and physical therapy.”

Because of the lack of interest in mechanical engineering, student C’s motivation in learning was relatively low, which he himself also recognized and admitted:

Student C: “If I do the sport and physical therapy, I would work harder than I am now because I don’t really enjoy mechanics.” “If I could do the sport and physical therapy, I would have worked a lot harder than I have this year. I would like regret it now. I think I’m going to find the exams hard, but I don’t want to do mechanics engineering.”

In summary, in this year 1 team, it can be seen that the individual differences in the reasons for choosing the degree programme reflected different extent of interest in engineering. The students who chose the degree programme based on their previous engineering experience, such as student A and D, had real interest in engineering, and would like to put much effort in the PBL teamwork; the students who chose the degree programme based on their subject strengths and had a vague understanding of realistic engineering, such as student B, was likely to put limited effort in the PBL teamwork when they felt the way of learning conflicted with their traditional way of learning and understanding (as discussed previously); the students who were constraint by their sponsorship and did not have interest in engineering, such as student C, their effort in the teamwork would be the least among the team, although they could complete a fair share of the teamwork.

2) Future career goals

In this team the individual differences in future career goals were related with those of the reasons for choosing the degree programme. For student A and D who chose the degree programme based on their interest in previous engineering experience, they had relatively clear goals in their future career.

Student A: “In the future, I want to be an engineer. I want to be involved in the motor sport industry or some such thing, so it’s just a type of learn that’s always done, engineering, maths and physics, something that I can imagine doing.”
Student D: “That was my goal. It was during college, I decided I wanted it - to study mechanical engineering and have a career in the military.”

Student C also had a relatively clear future goal of doing mechanical engineering although he did not like it, but he was not sure if he would like to do the military service.

Student C: “I don’t want to do it (military) forever. I see I would when I get into it, but I think we only have to do three years and then I can decide whether carry on into doing it or just for company.” “I would (do mechanical engineering), it’s my job. But I’m not sure who will be with.”

By comparison, student B’s future career goal was unclear; he was not sure if he would be an engineer, and a good degree was what he most wanted for his future:

Student B: “I don’t know what I’m going to do yet. That’s why I just want as a good degree as I can, so when I come out, sth. good can be open to me. You know, I’m not sure about my future life as an engineer or not. It’s sort of buying my time.”

It can be seen that whether clear or not, generally these future goals could have a positive effect on the design project teamwork because the good learning outcomes could benefit their future goals. Thus the individual differences in the future goals in this year 1 team had the same effect on the teamwork effectiveness.

3) Drives for learning in this design project module

The drives for learning in this design project module in the year 1 team fell into three categories: a) final assessment mark; b) sense of responsibly for the team; c) learning improvement.

For most team members, a good mark was the main drive of their learning, not only for the design project module, but for the whole degree programme as well.

Student A: “I think the drive of everyone is to do it well this year. I think really the drive is the mark at the end of this [year].”

Student B: “Just… marks, for the degree really. You know, the main drive of being here is to get me the marks as best as I can in the exams so that I can improve much.”

Student D: “Obviously … I hope I can get a good mark.”

The exception was student D. Because of his sponsorship, a good mark was not what he cared about. His standard concerning marks was just to pass the degree, which he thought was a common phenomenon among the sponsored students. For him, the drive of learning in this design project module was the responsibility he felt he had to take in the teamwork.
Student C: “If you are sponsored, as long as you pass your degree, and you are in. So I think quite a lot of people, [the] motivation [is] to get through with it because as long as they pass, they would get a job.” “I felt I have to do, not letting them down, and that’s why I have to do that.”

The same sense of responsibility for the team could also be found in other team members, such as student A and student B.

Student A: “At the end of the day, no one wants to let the rest of the team down.”

Student B: “Just, you know, making sure that I contribute really. I don’t like to be one person to let them down.”

However, it should be noted that the sense of responsibility in the year 1 team was partly resulted from the peer assessment to be taken at the end of the module. With the measure of peer assessment, the team members realized that they needed to make at least a fair contribution for the team, even if they did not like the teamwork, such as student B.

Student A: “I think this is the first project that is being peer assessed as well. So I think people made more effort this time because they know they need to pull the way and they need to contribute the team, otherwise the other people will not be really happy.”

Student B: “I was happy just to do my own fair share, but also know that, you know, if I did less, I probably get slightly worse mark because we assess each other.”

Student D was the only student in the team who regarded the learning improvement as his drive for learning besides a good mark or sense of responsibility. Here a comparison can be made between student B and student D in their understanding of the relation between learning improvement and marks. Student D believed that his own learning improvement could not be reflected in the marks but should be sensed by himself in practice; whereas student B held that the high marks represented the fact that he got improved. Thus, student D took learning improvement as his main learning drive while student B took the high marks as his main learning drive in the design project.

Student D: “I think it’s more important to me that I feel that I’ve improved rather than a high mark because I think my own improvement I won’t see it in the marks I get. I just know that when I come across next project I’ll be better rather than what the mark I can get.”

Student B: “The main drive of being here is to get me the marks as best as I can in the exams so that I can improve much.”
With the learning improvement as his main drive for learning, student D was the only student who could reflect on his learning after the design project and realized his weakness in the team learning which he wanted to improve.

Student B: “I just tend to stay quiet. In group I wasn’t active as you observed. It’s the way I’m in a group….There is sth. in there that I need to improve on.” “It’s sth. I’m not very good at, so it’s sth that I can learn from.”

In summary, in the three categories of learning drives in this year 1 team, a high mark and sense of responsibility for the team were common learning drives among team members which had a positive effect on their teamwork. Learning improvement as the drive for learning could help students reflect on their learning activities and improve themselves consciously, thus it had a positive effect on both the teamwork and personal learning improvement.

8.5.4.3 Preference to PBL
In this year 1 team, it was found that there were two reasons for the team members’ preference to PBL: one is the development of transferable skills; the other is better learning of knowledge.

For student A and D who had previous realistic engineering experience and sufficient engineering project experience, they compared the learning outcomes in PBL with that in the traditional way of learning mainly from the perspective of transferable skills. They preferred PBL because these skills could not be learnt in traditional way of learning.

Student A: “I think this project is the best to teach you the real life skills as opposed to the traditional sort. They teach work in the group, you know, developing ideas, real engineering as in what you will do in the real life.”

Student D: “I think it’s a better way of learning rather than the traditional like just lectures and teachers…because realistically if you go on with a job in engineering, you are not going to do lectures or doing exams, you are going to be doing, like group things, so it’s more like applicable in the career of engineering.”

For student C and E who did not have much previous engineering project experience, they preferred PBL because the knowledge could be learnt better than that in traditional way of learning.

Student C: “I … prefer it. I think you learn more doing in that way because you have to do it, you have to learn, [have to] remember how to use the machine, rather than just being told that.” “In lectures, not turning up the lectures doesn’t count for anything, whereas [in this project] you are making sth, like every bit you make, it’s more marks you are on it.”
Different from other team members, student B was the only one who did not like PBL. There are three main reasons for his negative attitude to PBL: a) possible occurrence of unequal teamwork allocation; b) personal preference for individual learning style; c) not used to the open nature of design projects.

a) Student B: “I’m not huge fund of that, just for sometimes you have non equal bears through work on different people, because it’s might quite different in a group, you end up sort of some people to do more work and others leave more in per air.”

b) Student B: “I’m not used to the socializing with people, because I just like to do in my own way. …I think it takes more for me to work in a group than on my own because when you in a self line you can just get on and do it yourself; now the issue is you are working in a group and you have to look up what others are doing. It adds an extra dimension. I’m not huge fond of it.”

c) Student B: “[I prefer traditional] lessons and exams because there is right or wrong answer in the end, like I prefer to be.” “It’s not as directed so it’s hard to know what is right or wrong, but the [traditional] exam is learning itself with questions. In exams you got certain things to learn. In rough design, you can design it not so well, incident work so much; but in exams, you can get marks for. It’s not easy to get things off, often.”

From the three reasons taken by student B, it can be seen that an underlying reason behind all these was that the value of the design project was not properly understood. Without previous engineering experience, student B seemed not aware of the value of teamwork in engineering profession, and as a student with good academic foundation (student B was an above average student), he had the tendency to stick to the traditional way of learning and felt uncomfortable to adapt himself to the new learning environment.

With the negative attitude, no effort was found in student B to change his way of learning as student D and E did, thus in the teamwork the personal improvement of student B would be limited although he made a fair contribution to the team:

Student D: “There is sth that I’m still not good at, just like the communication and teamwork phase, So obviously it’s sth that I can do to improve that.”

Student E: “It’s different way of learning things, in a sense I think you are needed to revise yourself if you are a team member or sort of the thing.”

Thus, it can be seen that in the year 1 team, the different understanding of PBL was closely related with the extent of previous engineering experience; the different understanding of the
value of PBL could result in different attitudes to PBL and traditional way of learning, which
could influence individual’s effort in their teamwork and further influence the whole team
effectiveness.

8.6 CONCLUSIONS
In this study, observations were made at individual differences of one first year team in their
PBL team learning, and subsequent interviews with individual team members were conducted at
the end of the PBL module. Based on the analysis of the individual differences and their effects
on the teamwork effectiveness at three levels, namely, interaction-based level, team-based level
and a priori level, the positive dynamic interaction between these individual differences were
identified and a good mode of dynamic interaction in PBL was presented. This study provided
the experimental observation for the PBL research, which could be a reference for the further
research on the internal dynamic interaction in PBL.

This study of individual differences in PBL is a necessary and useful supplement to the model
of PBL effectiveness which focused on the static conditions of parameters by means of
aggregating and averaging. Through this study, an initial exploration of the dynamic interaction
within PBL teamwork was made, which helped perfect the research methodology on the one
hand, and deepen the understanding of PBL on the other hand.
Chapter 9.

SUMMARIES AND RECOMMENDATION FOR FUTURE WORK

9.1 SCOPE OF THE PROJECT

The focus of this research is on the effectiveness of project-based learning (PBL) in engineering design. The scope of the project includes the definition of PBL effectiveness, the identification of the controlling parameters of PBL and the discovery of the optimal PBL.

In order to obtain quantitative findings, the initial assumptions of the research are proposed as follows:

1) The PBL effectiveness is measurable;
2) The PBL effectiveness is controlled by infinite parameters, including the observable and unobservable, the measurable and immeasurable, the controllable and uncontrollable.

The aim of this research is to find out important observable and measurable key parameters of PBL in order for teachers to implement and achieve the optimal effectiveness of PBL. Due to the complexity and flexibility of PBL, a novel research strategy combining quantitative and qualitative methods is presented for PBL analysis. By using this strategy, quantitative conclusions about the optimal PBL are obtained in the sense of statistics and some subtle characteristics of PBL involving individual differences which are not been taken into account in quantitative analysis are studied by proper qualitative methods.

9.2 SUMMARY OF THE METHODS, FINDINGS AND CONTRIBUTIONS

1) Proposing a well-defined problem on the key issue of PBL

The literature review in chapter 2 revealed a confusing and arguing situation in the implementation of PBL and the lack of consensus on its effectiveness. From the review it was found that it is not only necessary to know whether PBL is effective and what its effectiveness is, but also important to know how to implement PBL in a better, and even the best way. These two aspects are closely related and need to be taken into consideration at the same time in the research on PBL effectiveness. Nevertheless, very few studies have touched on both of these aspects at the same time. Furthermore, little research has been done on differentiating the
various ways of PBL implementation and providing measurable metrics of PBL effectiveness based on solid educational theories and rigorous research methodology.

2) Defining the PBL effectiveness from the perspectives of engineering lecturers and graduates

The study in chapter 4 dealt with the aspect of what PBL effectiveness is. In this chapter, studies were made to define PBL effectiveness from the perspectives of PBL teachers and engineering graduates. Varieties of the implementations were confirmed as what chapter 2 revealed, and general categories of PBL effectiveness in engineering design were identified. It was found that only knowing what the effectiveness of PBL was not enough, because the reasons for its effectiveness were still in the dark.

3) PBL models using parameters based on self-directed learning or learner engagement theories

In chapter 5, studies were focused on identifying and determining the key parameters of PBL which should be closely related with PBL effectiveness, and meanwhile should be quantifiable and controllable. Based on the educational theories of self-directed learning and learner engagement, two key parameters of PBL, self-directed learning and learner engagement, were identified, and ways of quantifying these two parameters were determined. With the key parameters of PBL determined and quantified, and with the PBL effectiveness categories defined in chapter 4, schematic models of PBL effectiveness were proposed, with the key parameters of PBL representing X axis and the PBL effectiveness categories representing Y axis. Thus, the two aspects – what the PBL effectiveness is and how to achieve the optimal effectiveness are both involved in the models. In this way, the optimal PBL effectiveness can be identified and measured.

4) Model verification: experiments and data analysis

With the schematic models of PBL effectiveness being built on the basis of self-directed learning theory and learner engagement theory, chapter 6 and 7 focused on the experiments for verifying them. The student self-reported survey was designed based on the proposed PBL effectiveness models and was administered among university engineering students across UK universities. The method of moving average was mainly used in analysing the data. Findings showed different trends of the relations between self-directed learning and PBL effectiveness, and between learner engagement and PBL effectiveness in different academic years. With the combination of the data in these 2D models, a 3D model of PBL was built through which the optimal PBL effectiveness in 3D were identified and measured and the interplay between different parameters were found.

Conclusions of the Thesis
5) Studying sub-categories of PBL effectiveness by using models and experimental data

In chapter 7, findings also included 1) the relation between sub-categories of PBL effectiveness, including design ability improvement and transferable skill improvement, with the two key parameters, namely, self-directed learning and learner engagement; 2) the relation between the sub-categories of self-directed learning, including private learning and team-based learning, and PBL effectiveness; 3) the relation between sub-categories of learner engagement, including behavioural learner engagement, affective learner engagement and cognitive learner engagement, and PBL effectiveness. These findings revealed the different trends of the relation between these sub-categories in different academic years, which helped deepen the understanding of the PBL model and provided further guidance for the achievement of the optimal PBL effectiveness.

6) Extra model parameters: further insight into modelling PBL

In chapter 7, besides the findings of the relation between the two key parameters and PBL effectiveness, the relation between some other parameters and PBL effectiveness were also studied, including design problem, lecture, tutorials and team dynamics. Findings showed the generally positive trends of the relation between these parameters and PBL effectiveness, and comparison was made across different academic years. In addition, the influence of previous engineering experience on the model of PBL effectiveness was identified. All these findings provided guidance for PBL implementation.

7) Qualitative study on the individual differences: supplement to quantitative method

The study in chapter 7 was mainly based on the static conditions of parameters by means of aggregating and averaging, in the course of which students’ individual differences involved in the learning process and the dynamic interaction of the individual differences in the teamwork was neglected. Thus, chapter 8 was focused on the dynamic interaction of the individual differences in PBL team learning. Findings presented a good mode of dynamic interaction of the individual differences at three levels, namely, interaction-based level, team-based level and a priori level. This study provided the experimental observation for the PBL research, which could be a reference for the further research on the internal dynamic interaction in PBL. This study was also a useful supplement to the model of PBL effectiveness, which helped perfect the research methodology on the one hand, and deepen the understanding of PBL on the other hand.
9.3 LIMITATIONS OF THE RESEARCH
Although the present work has made a substantial progress in understanding the PBL effectiveness, a number of limitations need to be considered regarding this research due to the complexity and flexibility of PBL.

First, the selection of parameters (X axis), assessment (Y axis) and history (hidden parameters) (see details in section 3.4 in chapter 3) is limited. Second, their data collection in experiments is also limited due to the limits of the research time, the number of design project courses and the involvement of students.

In terms of the first limitation, any extended models of PBL which involve more parameters would not change the findings and conclusions in the present research because they would not change the theoretical structure of the model.

In terms of the second limitation, more experiments based on the model of PBL in this research might cause slight fluctuation in the findings obtained from the data processing, e.g. the optimal SDL time value might be slightly affected. But the validity and reliability of the research methods and conclusions proposed in this research would not be affected because the present model of PBL is based on solid educational theories and rigid data analysis of sufficient experiments.

9.4 RECOMMENDATIONS FOR FURTHER WORK
The present research proposes an applicable methodology to analyse PBL and discover the optimal teaching/learning mode. It is noted that in theory PBL is controlled by infinite parameters. However, by using the proposed methodology, the present study demonstrates how pivotal parameters can be identified and how the corresponding optimal PBL can be discovered. Although there is limitation in terms of the number of parameters identified and the data collected in the present study due to the time limit of the project, the effectiveness of the proposed methodology is well verified and its potential is huge considering the large number of possible parameters in future research.

From the view of philosophy, on the one hand, using quantitative methods is an indispensable supplement to the qualitative methods for verifying the latter; on the other hand, it is an independent research tool itself which can have its own discovery/contribution and can stimulate and improve the qualitative methods. The present research has proved these philosophical thoughts. Therefore, the trend of future research should be seamless integration of quantitative and qualitative methods which can lead the study of PBL to a new level.
Concerning the development of the model of PBL, the findings in this research can apply to a wide range of PBL implementations for guiding and improving the PBL courses, and for further verifying the model. Furthermore, more parameters, assessment and history, e.g. the wider interaction of PBL with the rest of the programme of the study, can be probed, through which further discovery can be made of the interwoven structure of parameters, assessment and history of PBL and of their ultimate influence on the effectiveness of PBL.

From the research in this thesis, it can be found that PBL is a flexible teaching and learning approach in that the teacher can design a tailored course by controlling and making use of the parameters. In particular, from the optimal types of PBL found in this research and from the rational understanding of the parameters, the optimal PBL can be achieved in a systematic way. Therefore, there are advantages of PBL over the traditional lecture-based teaching and learning approach in this dynamic and diverse world. In the future, with the development of technology in data collection, processing and visualization, a unique platform could be provided for the development of personalized/student-centred education like PBL, with which a qualitative leap could be achieved beyond present imagination. Modelling of PBL is an indispensable tool which can make use of the technology and help realize the future development of PBL as part of personalized/student-centred education.

9.5 CONCLUSIONS

The present research proposed a novel methodology for analysing PBL. The parameters controlling the effectiveness of PBL and the underlying mechanisms are studied by mathematical model. To the author’s knowledge, it is first time that the optimal PBL is reported by using quantitative method. Moreover, qualitative method is used seamlessly to supply the mathematical model with subtle details on individual differences in PBL. This quantitatively-qualitatively-combined strategy opens up a new horizon for further PBL study.
References


References


References
References


References


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References


References


Appendix 1

Interview on teachers in PBL design modules

<table>
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<tbody>
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<td></td>
</tr>
<tr>
<td>Year / Part of course</td>
<td></td>
</tr>
<tr>
<td>Length of the module</td>
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**Information of the Module**

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<tr>
<td>Any module prerequisites</td>
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**Information of the design project**

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<tbody>
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<td>beginning  middle  end of the term</td>
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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>_______________fictional, student derived</td>
</tr>
<tr>
<td>_______________fictional, industry derived</td>
</tr>
<tr>
<td>_______________fictional, instructor derived</td>
</tr>
<tr>
<td>_______________Real design competition</td>
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**Information of students and staff**

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<tr>
<td>Team size</td>
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</tr>
<tr>
<td>team formation</td>
<td></td>
</tr>
<tr>
<td>How to form the teams and why?</td>
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<table>
<thead>
<tr>
<th>Number of staff involved (is there an acceptable / desirable ratio)</th>
<th>tutor</th>
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<td></td>
</tr>
<tr>
<td>_______________external professionals</td>
<td></td>
</tr>
<tr>
<td>_______________teaching assistants</td>
<td></td>
</tr>
<tr>
<td>_______________other</td>
<td></td>
</tr>
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</table>

**Information of ways of teaching**

**Lecture**

| How much work to be done by teachers? |                      |
| Contact time timetabled (hours):     |                      |
| The time to deliver the lecture:     | Before / after / parallel the project? |

<table>
<thead>
<tr>
<th>What is the proportion of lectures in the whole module?</th>
<th>Reasons for the proportion.</th>
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<tbody>
<tr>
<td>How effective is the lecture? Any problem?</td>
<td>How to deal with the problem?</td>
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<tr>
<td>------------------------------------------</td>
<td>--------------------------------</td>
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<tr>
<td>Tutorial</td>
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<tr>
<td>How do you tutor the students?</td>
<td></td>
</tr>
<tr>
<td>Some details. Any problem?</td>
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</tr>
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<td>Student learning outcomes</td>
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<td>What learning outcomes do you emphasize</td>
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</tr>
<tr>
<td>most in this module?</td>
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<tr>
<td>What abilities do you find the students</td>
<td></td>
</tr>
<tr>
<td>develop well most effectively?</td>
<td></td>
</tr>
<tr>
<td>What abilities did the students develop</td>
<td></td>
</tr>
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<td>with difficulties? Reasons?</td>
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<td>Which part(s) of the module is (are)</td>
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<tr>
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<td></td>
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<tr>
<td>/ skills? And Why?</td>
<td></td>
</tr>
<tr>
<td>Assessment</td>
<td></td>
</tr>
<tr>
<td>How do you assess the students? Reasons?</td>
<td></td>
</tr>
<tr>
<td>Exams</td>
<td>Writing reports</td>
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<td>Oral presentations</td>
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<td>Web-PA</td>
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<td>Web-PA</td>
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<td>Other</td>
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<tr>
<td>How are the projects done by students?</td>
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<tr>
<td>YOUR understanding of design</td>
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<tr>
<td>“Design cannot be taught.”</td>
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</tr>
<tr>
<td>What’s your understanding of design?</td>
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</tr>
<tr>
<td>What can be taught and what cannot be</td>
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</tr>
<tr>
<td>taught?</td>
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<td>What do you think is the best way to</td>
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<td>teach design?</td>
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<td>What should be emphasized in the</td>
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<td>engineering design teaching?</td>
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<tr>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 2

The effects and effectiveness of group design projects from the perspective of engineering graduates

Mingyi Gao  M.Gao@lboro.ac.uk
Engineering Centre for Excellence in Teaching and Learning, Loughborough University

Aim:
The aim of this interview is twofold: firstly, it is to study the effects of the group design projects on the engineering graduates’ work; secondly, it is to find out the relatively effective group design project implementations from engineering graduates’ perspectives.

Please note:
The focus of the interview is particularly on the undergraduate group design projects. All the data collected from the interview will be kept in strict confidence and will be used only for the research purpose.

Biographical information
Please fill in your biographical information in the following table before answering the interview questions:

<table>
<thead>
<tr>
<th>Name</th>
<th>Your undergraduate degree program</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The year of graduation</td>
</tr>
<tr>
<td></td>
<td>Your final degree</td>
</tr>
<tr>
<td></td>
<td>Any industrial experience during your university study?</td>
</tr>
<tr>
<td></td>
<td>Your present occupation</td>
</tr>
<tr>
<td></td>
<td>Is your present occupation relevant to engineering? (Please state Yes or No)</td>
</tr>
</tbody>
</table>

Please go to next page
Interview questions:

Please recall and think about the group design projects you did in your undergraduate engineering degree course.

1. How many group design projects did you do in each year of the design course?

2. How is this “learning by doing” way of learning useful to your present work?

3. Did you work in a team or teams in the group design projects? What is your opinion on the way(s) of team formation in group design project learning from your present perspective?

4. What kind of role(s) did you generally play in teams, eg. the leader, active supporter, quiet supporter, passive participant, etc.? Please state the reasons.

5. How is the design teamwork experience useful to your present work?

6. Generally, what knowledge, abilities and/or skills did you develop which are useful to your present work? Please explain in some details.

7. Looking back, of the total time (100%) you spent in completing the design project courses, how much time do you think should be allocated for guidance from teachers (lecturers, tutors, mentors or industrial professionals, etc) both in and outside of class in each year of the group design project course? Please state a rough optimal percentage and give brief explanations.

<table>
<thead>
<tr>
<th>Year</th>
<th>Optimal percentage of guidance</th>
<th>Reasons</th>
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<td>Year 3</td>
<td></td>
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<tr>
<td>Year 4</td>
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</tbody>
</table>

8. If you had to rate the usefulness of the design courses to your present work, where would you put them in the following scale? Please highlight one in the following scale and give brief reasons for your choice.

<table>
<thead>
<tr>
<th>Usefulness</th>
<th>0= none;</th>
<th>5=average useful;</th>
<th>10= totally useful</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 1 2 3 4 5 6 7 8 9 10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Appendix 2
9. Is the amount of group design projects in your undergraduate education appropriate for your present work? Please highlight one from the following 5 point scale and give brief reasons for your choice from your present perspective.

<table>
<thead>
<tr>
<th>Reasons from your present perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Too many</td>
</tr>
<tr>
<td>4. A little bit too many</td>
</tr>
<tr>
<td>3. Appropriate</td>
</tr>
<tr>
<td>2. A little bit few</td>
</tr>
<tr>
<td>1. Too few</td>
</tr>
</tbody>
</table>

10. Looking back, what would you change in your group design project courses so they are more useful for your present work?

Thank you very much for your time and cooperation!
Appendix 3

Student Survey
---On project-based learning in design project modules

This survey aims to scope the different ways of project-based learning (PBL) in engineering design modules. The focus of this study is on the impacts of these different ways of PBL on learning and teaching. You have been given this questionnaire because you are taking a project-based module. Thank you very much for taking the time to respond.

Before you begin, please note:
- It will take 5 minutes (approx.) to complete the survey.
- You are free to withdraw from taking part in this survey at any time.
- This study adheres to the University’s ethical guidelines and information gathered will be kept under the strictest of confidence.
- If you choose to, you will have the opportunity at the end to be entered into a prize draw.

SECTION 1. Background Information

Your gender (please tick)

| Male ☐ | Female ☐ |

1. Before the present module started last year, had you had any previous experience of engineering design projects in school/college/university? (Please tick)

| Yes ☐ | No ☐ |

If YES, please continue; if NO, please go to question 2 directly.

1 a. Please state the number of previous design projects you have undertaken (team or individual).

| Team design project(s) | Individual design project(s) |

2. Besides this present module, have you had any other design project module last semester? (Please tick)

| Yes ☐ | No ☐ |

3. Before the present module started last year, had you undertaken any industrial or work placement experience related to engineering? (Please tick)
If YES, please continue; if NO, please go to question 4 directly.

3 a. The year you did your last engineering work placement __________

3 b. The duration of your most significant engineering work placement experience was __________ days / weeks /months (delete as appropriate)

Please provide further details. (optional)
Eg: Sandwich placement; summer placement, etc.

1. Have you had any non-engineering project experience?

2. If YES, Please describe briefly. (optional) eg: individual or team; what subject, etc.

SECTION 2. Your Current Project Module

We are interested in knowing the amount of work involved in completing this module. Accordingly, please answer:

5. Of the total time you spent in completing the present design module last year, what is the proportion of the time you ACTUALLY spent on each activity listed in the table? (Please state the approximate percentage)

<table>
<thead>
<tr>
<th>Activities</th>
<th>Proportion of time (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Listening to lectures</td>
<td>%</td>
</tr>
<tr>
<td>b. Being supervised by or discussing with teachers (lecturer, tutor, mentor, industrial professionals, etc) in groups both in and outside of class</td>
<td>%</td>
</tr>
<tr>
<td>c. Discussing individually with teachers (lecturer, tutor, mentor, industrial professionals, etc) both in and outside of class</td>
<td>%</td>
</tr>
<tr>
<td>d. Studying/working in groups without supervision from teachers (lecturer or tutor, industrial professionals, etc.) both in and outside of class</td>
<td>%</td>
</tr>
<tr>
<td>e. Individual private study (eg. searching literature, reading materials, writing reports, preparing presentation or exam, etc)</td>
<td>%</td>
</tr>
<tr>
<td>f. Other (Please specify)</td>
<td>%</td>
</tr>
<tr>
<td>Total proportion of time</td>
<td>100 %</td>
</tr>
</tbody>
</table>
6. To what extent do you think THIS MODULE has improved your learning categories listed in the table? (Please tick) 0= no improvement; 1= little better than at the start of this module; 2= marginally better; 3= slightly better; 4= some improvement; 5= improvement; 6= great improvement

<table>
<thead>
<tr>
<th>Learning categories</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The ability to define and formulate a design problem</td>
<td></td>
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</tr>
<tr>
<td>2. The ability to generate concepts/solutions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. The ability to evaluate others’ concepts/solutions</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. The ability to refine concepts/solutions in design process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. The ability to produce graphical and/or visual representations</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>6. The ability to utilise ICT skills (e.g. CAD, MS-office, etc)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>7. The ability to use a variety of sources to find information</td>
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<td></td>
</tr>
<tr>
<td>8. The ability to work as an effective team member</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>9. The ability to communicate effectively in technical report writing and/or oral presentations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. The ability to learn independently</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. The ability to manage/organize time efficiently</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. The ability to apply engineering science to a design problem</td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

7. To what extent are you satisfied with the whole module? (Please tick).

<table>
<thead>
<tr>
<th>Greatly unsatisfied</th>
<th>unsatisfied</th>
<th>Slightly satisfied</th>
<th>Neither satisfied or unsatisfied</th>
<th>Slightly satisfied</th>
<th>Satisfied</th>
<th>greatly satisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
</tbody>
</table>

8. Your final score in this design module last semester is ____________

A prize draw will be held after the collection of the questionnaire. If you wish to be entered, please give your ID number (which will be used ONLY for this purpose and will be kept in strict confidence).

Your ID number ______________________

THANK YOU very much for your time and cooperation!

Please return the questionnaire to:
Mingyi Gao
engCETL
Loughborough University
Loughborough LE 11 3TU

Appendix 3
Appendix 4

Survey on the Effectiveness of Self-directed learning in Group Design Project Modules

This survey aims to find out the way students' self-directed learning is influenced in project-based learning (PBL) in engineering design modules. We are constantly seeking to improve your learning experience. Thank you very much for taking the time to respond.

Before you begin, please note:
✧ This survey is anonymous and will be used only for research purposes.
✧ It will take 10 minutes (max.) to complete the survey.

Section 1 Background Information

1. Your gender (Please tick) Male ☐ Female ☐

2. The name of your degree program (Please state) _____________________

Section 2 Your group design project module

Please answer the following questions based on one of the most recent group design project modules you have taken.

3. Before you took this group design project module, did you have any previous industrial experience like Sandwich courses or Summer placement, etc.? Yes ☐ No ☐

3.1 If yes, please state the time and duration of your industrial experience: __________________________

4. In which degree year have you taken this module? (Please state) __________________

In this survey, we attach great importance to the time allocation you had in your group design project module. Please reflect your time allocation carefully and answer question 5.

5. Of the total time (100%) you spent in completing the design project module, please estimate the proportion of time you ACTUALLY engaged in each activity listed in the following table.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Approximate proportion of ACTUAL time you spent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Listening to lectures.</td>
<td>%</td>
</tr>
<tr>
<td>b. Being supervised by or discussing with teachers (lecturer, tutor, mentor or industrial professionals, etc) in groups both in and outside of class.</td>
<td>%</td>
</tr>
<tr>
<td>c. Discussing on your own with teachers (lecturer, tutor, mentor or industrial professionals, etc) both in and outside of class.</td>
<td>%</td>
</tr>
<tr>
<td>d. Studying/working in groups without supervision from teachers (lecturer or tutor, industrial professionals, etc.) both in and outside of class.</td>
<td>%</td>
</tr>
<tr>
<td>e. Individual private study (eg. searching literature, reading, writing reports, preparing presentations or exams, etc).</td>
<td>%</td>
</tr>
<tr>
<td>f. Other (eg: discussing with peers by email, informal chatting with peers or friends, etc.).</td>
<td>%</td>
</tr>
</tbody>
</table>

Total proportion (a+b+c…+f) should add up to 100%

(Please ensure that the total percentage of time, that is a+b+c…+f, should add up to 100%)

Appendix 4
The following questions from question 6 to question 10 are about your opinions on the different factors involved in your group design project module. Please choose the one that applies.

6. To what extent do the following statements describe the design problem in this design project module?

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neither Agree Nor Disagree</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. The design problem was interesting enough for me to put effort on it.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>b. The design problem was challenging for my current knowledge and experience.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>c. The design problem was closely related to my future career goals.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

7. To what extent do the following statements describe the lectures in this design project module?

If there was no lecture in your design project module or you chose not to attend lectures, please continue with question 8 directly.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neither Agree Nor Disagree</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. The content of lectures facilitated my project work.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>b. The lectures were useful to me in the engineering technical aspect.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>c. The lectures were useful to me in the design knowledge and skills aspect.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>d. The lectures were useful to me in the soft knowledge aspect (eg: teamwork skills, presentation skills, etc.).</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

8. To what extent do the following statements describe the tutorials in this design project module?

Here the tutorial means the direct supervision from the teachers (or tutors, etc.) in and/or outside of class.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neither Agree Nor Disagree</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. The tutorials helped address my questions well.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>b. The tutorials stimulated my critical thinking.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>c. The tutorials facilitated my independent learning.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

9. To what extent do the following statements describe your teamwork in this design project module?
Appendix 4

To what extent do the following statements describe your learning in this design project module?

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neither Agree Nor Disagree</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Teamwork went well generally.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. The task distribution in the team was fair.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Teammates completed their fair share of work on time.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. The communication between team members was good.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. The team meetings were efficient.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. The discussion in team meetings was stimulating.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. Team conflicts could be settled successfully.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. I learned much from my teammates.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10 To what extent do the following statements describe your learning in this design project module?

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neither Agree Nor Disagree</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I like the way of team learning in the project.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. I was active in the team discussion.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. I took a leadership role in the teamwork.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. I took more responsibility for the project than my teammates.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. I was able to manage my time well in this project.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. I often reflected on the progress of my work.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. I had confidence to do my share of work well on my own.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. I like meeting challenges in my study.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>i. I prefer traditional teaching methods (eg: lectures + exams, etc.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

11. To what extent your learning was improved in the design project module?

*Please choose one from scale 0 (no improvement) to scale 10 (total improvement)*

<table>
<thead>
<tr>
<th>Scale</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>5</td>
<td>Average improvement</td>
</tr>
<tr>
<td>10</td>
<td>Total improvement</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Statement</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Generating design concepts/solutions ability</td>
<td>0</td>
</tr>
</tbody>
</table>
b. Evaluating design concepts/solutions ability

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

c. Knowledge application ability (eg: engineering science, mathematics, etc.)

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

d. The ability to work effectively in a team

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<th>6</th>
<th>7</th>
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<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

e. Time management skills

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

f. Independent learning ability

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

g. The ability to reflect on and monitor the project progress

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

h. The ability to deal with difficulties in your own share of work

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

i. The ability to deal with difficulties in the teamwork (eg: others work behind schedule; team conflicts, etc.)

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

j. Oral and/or written communication ability.

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

12. What method if any was used to allocate individual marks in the assessment of your group design project work? (Please select all that apply)

<table>
<thead>
<tr>
<th>Method</th>
<th>o</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>o</td>
</tr>
<tr>
<td>Paper-based peer assessment</td>
<td>o</td>
</tr>
<tr>
<td>Individual sections in reports</td>
<td>o</td>
</tr>
<tr>
<td>Web-based peer assessment (Web PA)</td>
<td>o</td>
</tr>
<tr>
<td>Other (Please specify)</td>
<td></td>
</tr>
</tbody>
</table>

13. Do you think this way of assessment is fair for you? Yes ☐ No ☐

13.1 Please explain your choice: (Optional)

14. Your final score in this design module: (Please give the exact number if possible, eg. 60) ____________

15. Your team name and /or team number: _______________________________

16. Your contact email address (optional) _______________________________

Thank you very much for your time and cooperation!
Appendix 5

Interview on the individual & group self-directed learning in design project modules

This interview is about the self-directed learning in design projects and its effectiveness. My focus is on the individual differences in your teamwork and your individual learning. Please talk about your experience mainly based on your design project module.

Session 1: Background information
1. Why did you choose this degree program? Is this your future goal? (What are you going to do in the future?)
2. Do you have any previous experience in group design projects? Is there any difference between this one and your previous one? Is there any other group design module you take parallel with this one?

Session 2: learning preference
3. Do you like this “learning by doing” way of learning? What do you think you have learnt well in this module?

Session 3: your team work
5. How do you comment your team work generally?
6. What role did you take in this teamwork (follower, active, passive)? Are you satisfied with this role?
7. Is the leader effective? Is what aspects? Have you ever thought of changing the role in the course of the project?
8. Do you want to take the same role in the future project learning or your future career, or try other roles? Do you think your present role is good or not for your learning?
9. What is your contribution to the team and project? How do you comment your work in the group?
10. Is what you did you are good at, or poor at in the share of work you did?
11. What improvement did you make? Was what you are good at improved better, or was what you are not good at improved to some extent?
12. Did you get any help from your teammates? Did you learn anything useful from them?
13. Is the teamwork useful to you? Is it also useful to other teammates?

Session 4 individual learning
14. Are the design projects challenging to you? In what aspects if yes; if no, why not?
15. What is the drive of your learning in this design project? (catch up with others, marks, etc)
16. How do you think about your self-directed learning? In what aspects your SDL is improved? For example, managing time, searching resources, etc.

Session 5: Project-based learning and traditional way of learning
17. In the teamwork, is the allocation of work fair? Do you prefer to do more of the work
to practice yourself, or do the same or less amount of work since your team members may get similar marks from the project?

18. In traditional approach, if you work hard, you can get good learning outcomes, if you can work less, you get poor result; but in the design project, you may do much, but the result may not as good as you expect; you can also do less than others, because peers can help anyway. How do you look at this?

19. Compared with the traditional approach, lectures + exams, which way of learning do you prefer? Do you want to do more design projects like this in the future learning?

20. Any suggestions for the design project module?

Thank you very much for your time and cooperation!
Publications

