Investigation of Assessment Methods for Measuring the Effectiveness of Student Design Learning

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Abstract

Investigation of Assessment Methods for Measuring the Effectiveness of Student Design Learning

Shahriar Taheri

Deep learning approach in educational context is focused on analyzing ideas, and creating a strong connection between the ideas and prior knowledge. A Problem-Based Learning (PBL), considered as students' deep learning approach, is a widely-adopted educational strategy designed to teach students to use their engineering knowledge to solve the real-life engineering problems. The goal of this thesis is to investigate of assessment methods for measuring the effectiveness of students' learning under a flying house design session which is a PBL teaching method. To do so, the Environment Based Design (EBD) approach is used to determine assessment criteria. Two assessment methods (i.e., Study Process Questionnaire (SPQ), Logos Comparison Task (LCT)) have been applied to two groups of students with and without EBD knowledge. Through the investigation and analysis, the results indicate a significant effect of EBD knowledge and skills on the LCT grades. However, no major effect of students' learning approach (SLA) and interaction between EBD and SLA has been detected. Similarly, no linear relationship between students' deep learning approach and higher LCT grades has been found.

Acknowledgments

Firstly, I would like to acknowledge my thesis advisor Dr. Yong Zeng. The door to Prof Zeng office was always opened for me. Moreover, he helped me to write this thesis with his precious and knowledgeable comments and guidance. My academic achievements under Dr. Zeng supervision was not all I have got. He also taught me how to think big and how to improve my perception. In addition, his patience in complications taught me how to deal with threats and how to use opportunities. For all these reasons and so many others, I owe an immense gratitude to Dr. Zeng from the bottom of my heart for all he has done.

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Finally, I must present my thesis to my parents. Their continuous support always remind me that I am not alone. They taught me how to stand up after failure. The words are drastically incapable of expressing my debt of gratitude to them. BE GREEN FOR EVER.

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Chapter 1

Introduction

1.1 Research Problems and Motivation

The motivation of this research work is to explore the word ”measurement”. In order to find out the significance of measurement and how it can be realized, the following fundamental questions need to be answered:

(1) Why to measure?

(2) What is measurement?

(3) What to measure?

(4) How to measure?

The answer to the first question will explain the importance of measurement which is the main goal of this research work. To have a better understanding of the importance of measurement, here are several well-known scientists have quoted on it. For instance, ”*measure what is measurable, and make measurable what is not so*” said Galileo Galilei, ”*what gets measured, gets managed*” noted Peter Drucker and finally, ”*if you can not measure something, you can not control it. When you can measure what are speaking about, and express it in numbers, you know something about it*” believed Lord Kelvin, to name a few. In view of this, the sensitivity and significance of measurement need to be observed.

To answer the second question, measurement is defined as an underlying procedure in which surefire information is achieved (Mari, Carbone, & Petri, 2012). Measurements can be utilized in order to comprehend and illustrate a phenomenon in the nature, since it is a foolproof fundamental information (Finkelstein, 2005). As a tool, it has the power to descriptively project the attributes and features of the real world articles and phenomena through signs on the empirical process (Finkelstein, 2009). This tool provides ways to justify and reason about events that occur in the world (Finkelstein, 2003, 2009).

Measurement paradigm has evolved from its usage in natural science and grown by its power in describing human behaviors and mind (Finkelstein, 2005). Measurement is capable of monitoring patterns and evaluating experiments to determine if they are true or not (Kelvin, 1883). In addition, altering something deliberately would be much easier when it can be assessed with the knowledge of how much of it is available (Drucker, n.d.). The measurement development was initiated and developed by Helmholtz and Hoelder, and presented in detail in the works of Campbell through physical science and it was stretched to practically all realms of human knowledge (Finkelstein, 2009).

The third question aims to find answers for key question ”what to measure”. The *what* word refers to attributes or characteristics of an event, object, or a system (Rossi, 2007). The measurable characteristics and attitudes are named ”*quantity*”. In contrast, those that can not be assessed are called ”*quality*”. In the third question, metrics which have to be measured are identified and selected. To this end, various methods have been used to determine principal metrics in terms of the context under debate and aspects which has to be quantified or qualified.

In the last part of measurement, the fourth fundamental question, how to measure?, has to be answered in order to determine the devices, methods, or techniques which are used to measure the metrics. Depending on the measurement purpose and measurement type (i.e., qualitative, quantitative), measurement method and device can be chosen accordingly.

1.2 Objectives and Contributions

The main contributions of this work are as follows:

(1) Identifying the criteria which are significant to students' learning by using Environment Based Design (EBD).

(2) Investigating different methods of students' learning measurement in order to measure the effectiveness of students' learning.

(3) Collecting and analyzing data in order to determine the relationship between EBD knowledge, students' learning approach, and students' learning outcomes.

The students' learning measurement is conducted under the influence of a flying house design session as a PBL teaching method to see how it affects the student learning.

Let us consider education as a process that turns inputs into outputs (Antony, 2014). In the context of education, student learning is an output. Hence, identification of inputs needs to be discussed. In other words, from the cause and effect point of view, student learning is an effect of a cause or causes. The causes have to be pinpointed in order to change, manage, control, or measure the output (i.e., student learning). Therefore, the inputs of educational system and causes which are able to influence the student learning from diverse points of view are studied as follows:

- Teaching methods and context.
- Cognitive domains.
- Affective domains.

In the presence of the flying house design session as teaching context, cognitive and affective domains of student learning are measured. For this purpose, two methods are examined to measure metrics which are able to affect student learning. In particular, some methods have to be appointed in which they are capable of capturing and covering cognitive domains and affective domains of learning and to tackle the problem at hand. To this end, two methods namely, Study Process Questionnaire (SPQ), Logos Comparison Task (LCT) are investigated based on the cognitive and affective domains criteria.

1.3 Thesis Organization

This thesis is organized as follows:

Chapter 2 presents associated literature review, in which different learning approaches are described. Moreover, Environment Based Design (EBD) methodology as the theoretical foundation is explained. Afterwards, an introduction regarding assessment methods is presented. In Chapter 3 an EBD approach is employed in order to determine students' learning assessment criteria. Chapter 4 introduces a flying house design session as a case study and two different assessment methods to measure the effectiveness of students' learning. This chapter also investigates the usage of introduced methods in the flying house design session in terms of usefulness for measuring determined assessment criteria. In Chapter 5, the results related to the students' learning effectiveness is presented. Chapter 6 concludes the thesis and presents the future directions of students' learning measurement.

Chapter 2

Literature Review

In general, a real engineer is *one who has attained and continuously enhancing technical, communications, and human relations knowledge, skills, and attitudes, and who contributes effectively to society by theorizing, conceiving, developing, and producing reliable structures and machines of practical and economic value*(p. 4) (Crawley, 2014). Likewise, engineering *is about making products and servicesmaking things better, safer, more reliable, with improved quality and performancethat meet a specification, and completing the project within a prescribed budget and schedule, while keeping a customer happy* (p. 1) Hoffman (2014). The goal of engineering education is to deliver successful engineers through equipping students with needed knowledge (Crawley, 2014).

As the technologies are developed and the global industry is changed, companies and industries begun to address the requirement for restructuring by evolving perspectives of the desired engineering attributes (Crawley, 2014). To do so, they are looking for graduating engineers with the abilities not only in the technical domain but also in communication and team work (Ditcher, 2001; Handbook, 2008). Employers are looking for graduate students that initiate in self-directed learning and capable of meeting deadlines with a minimum supervision. In addition, employers wish to have employees with a good understanding of how an organization would be fitted to the society (Evers & Rush, 1996). In other words, employers expectation has changed, thus they need graduate students with

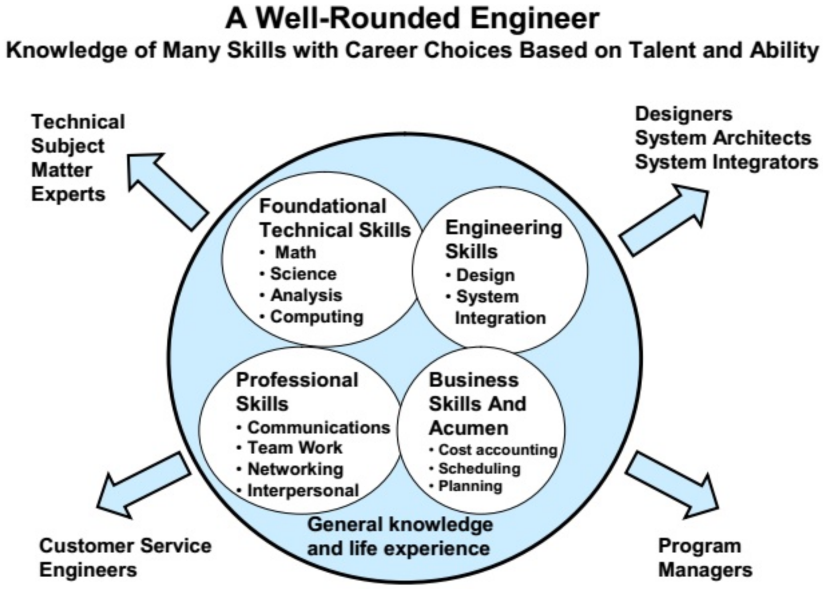

Figure 2.1: The well-rounded engineer of the 21^{st} century (McMasters & Komerath, 2005)

power of synthesis and analysis information, and students that are capable of making critical decision and taking best possible course of action. Accordingly, those exceptions necessitate possession of a powerful communicability, flexibility, and determinability (Wingfield & Black, 2005).

Due to these changes in requirement for students and to meet with them, administrators in education decided to develop the productivity of classrooms experience to make their students suited for the business world by creating an improved version of teaching method (Michel, 2009). Moreover, U.S. Accreditation Board for Engineering and Technology (ABET) proposed that all U.S engineering schools have to be held responsible for the knowledge, skills and professional values engineering students acquire (or fail to acquire) in the course of their education (Rugarcia, 2000). Besides, engineering departments enforced to prove that along with gaining solid science, mathematics and engineering knowledge, their students would grasp communication, multidisciplinary teamwork, and lifelong learning skills and awareness of social and ethical considerations associated with the engineering profession (Felder, 1998). The Partnership for 21st Century Skills mentions that four components are needed for students' success in both their studies and careers: critical thinking and problem solving, communication, collaboration, creativity, and innovation (Partnership for 21st

Desired Attributes of an Engineer (from Boeing Aircraft)
A good understanding of engineering science fundamentals –Mathematics (including statistics) –Physical and life sciences –Information technology (far more than computer literacy)
A good understanding of design and manufacturing processes (i.e., understands engineering)
A multidisciplinary, systems perspective
A basic understanding of the context in which engineering is practiced –Economics (including business practice) –History –The environment –Customer and societal needs
Good communication skills –Written –Oral –Graphic –Listening
High ethical standards
An ability to think both critically and creatively –Independently and cooperatively
Flexibility. The ability and self-confidence to adapt to rapid or major change
Curiosity and a desire to learn for life
A profound understanding of the importance of teamwork

Table 2.1: Desired attributes of an engineer adopted from (Hoffman, 2014; McMasters & Komerath, 2005)

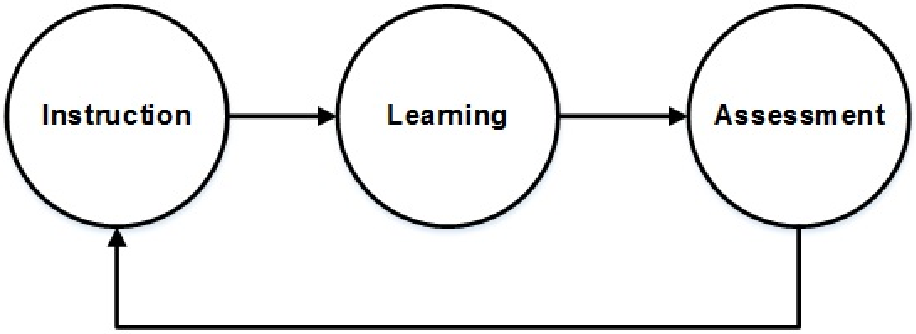

Figure 2.2: Learning science process (Mayer, 2011)

Century Skills, 2010, p. 2) (Evers & Rush, 1996).

Hence, effective learning and teaching approaches have to be studied as the main parts of an educational process. After that, the effectiveness of learning has to be measured to guarantee that students are ready to meet the employment requirements after graduation.

2.1 Teaching and Learning Approaches

Educational process can be summarized into three main elements as depicted in Figure 2.2 (Mayer, 2011).

According to the process, educational systems need to implement effective instructions in order to nourish learners for achieving substantial desire changes defined as learning. Assessment is a key factor to examine whether desired changes occurred or not as well as to provide a feedback loop for instruction to improve it toward being more effective. Considering the significance of the term (learning), a fully clear definition of learning is required.

2.1.1 Conceptions of Learning

The U.S. Department of Transportation: Federal Aviation Administration (Handbook, 2008) proposes different definitions of learning as follows:

(1) A change in the behavior of the learner as a result of experience. The behavior can be physical

and overt, or it can be intellectual or attitudinal.

(2) The process by which experience brings about relatively permanent change and behavior.

(3) The change in behavior resulting from experience and practice.

(4) Gaining knowledge or skills, or developing a behavior, through study, instruction, or experience.

(5) The process of acquiring knowledge or skill through study, experience, or teaching. It depends on experience and leads to long-term changes in behavior potential. Behavior potential describes the possible behavior of an individual (not actual behavior) in a given situation in order to achieve a goal.

(6) A relatively permanent change in cognition resulting from experience and directly influencing behavior.

Moreover, M.E.Gredler believes that learning is a multi-aspects process in which individuals normally fail to properly appreciate it but the moments they face the sophisticated tasks (Gredler, 1997). The concept of learning is a hypothetical construct which is not noticeable directly, but only can be detected from observable behaviors. Learning refers to everlasting changes in individuals' behavior performance. However, only changes that are associated with past experiences can be accepted as learning (Gross, 2015). Bigge and Shermis define learning as a long lasting change which happens in an individual's life that is not acquired as a birth moment inheritance(Bigge, 1982). This change can come in different forms (i.e., change in behavior, insights, perception, motivation, or a blend of them) which is occurred during the gaining experiences (Bigge, 1982). From the psychology standpoint of view, according to (Anderson, 1995a) and (coon, 1983) learning is defined as a process in which relatively permanent changes happen in behavior potential which is an experience (Gross, 2015).

Human learning can happen as a result of practicing, going to school, personal improvement, and education that can be strengthened by motivation and purpose. The science of how this learning happen called learning theory. This theory presents a conceptual framework in which gaining, processing, and retaining knowledge are studied during the learning process (Simandan, 2013).

Prior experience, affection, and cognitive are the principal parts of the achieving and altering process of understanding, knowledge, and skills (Illeris, 2002; Ormrod, 2011).

2.1.2 Learning Types

Learning comes in various types and formats as follows:

(1) Non associative learning
  - Habituation
  - Sensitization

(2) Associative learning
  - Operant conditioning
  - Classical conditioning
  - Observational learning
  - Imprinting

(3) Play

(4) Enculturation

(5) Episodic learning

(6) Multimedia learning

(7) E-learning and augmented learning

(8) Rote learning

(9) Meaningful learning

(10) Informal learning

(11) Nonformal learning

(12) Nonformal learning and combined learning

(13) Tangential learning

(14) Dialogic learning

(15) Incidental learning

All of kinds of learning and many others which are not mentioned can be easily considered as two major learning point of view which are:

(1) **Passive learning:** In this learning method, the lecturer gives the lecture in which student receive information through them without getting feedback from the instructor. Therefore, students have to apprehend knowledge passively from the instructor and lecture and try to retain the information from the lecture (Michel, 2009; Wingfield & Black, 2005).

(2) **Active learning:** This type of learning leads students for being more involved in classroom (Wingfield & Black, 2005). Hence, this type of learning tends to be more effective due to higher engagement in the learning and the learning experience would be stronger than the passive learning (Labinowicz, 1980).

Considering the characteristics of passive and active learning, two dominant learning approaches are evolved from them which are known as a student's surface and deep approach respectively (Crawley, 2010; Hay, 2007; Marton & Säljö, 1976; Ramsden, 2003).

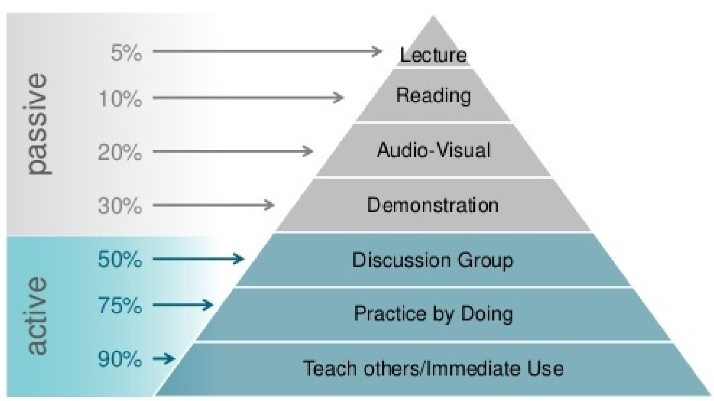

Figure 2.3: Passive learning vs active learning (Mayer, 2011)

Roughly speaking, a surface approach concerns with *what the students refer to* (i.e., merely trying to reproduce material passively) and focusing on words and signs (Ramsden, 2003). Surface learning represents the external learning process in which students tend to concentrate more on knowledge without attempting to apply it. The surface approach emphasizes more on inefficient studying without perusing a marked purpose. As a result, the level of satisfaction is considerably lower in a surface approach (Diseth, 2001; Ditcher, 2001). Furthermore, surface approach followers only focus on memorizing and imitate material in order to pass the exams but they don't necessarily fully acquire or understand the material. Therefore, the surface approach is associated with lower marks for a given study time. In addition, the surface approach makes the learning and studying process a toil as it requires a lot of memorization. Hence, students feel pressure and dissatisfaction in study time (Ditcher, 2001). In this situation, students are discouraged to get involved with concepts which are acting as a negative feedback loop. Thus, surface learning is just memorizing some facts without the capability of making connections between them (MacIsaac, 2015). To wrap up, a surface approach is about the quantity in absence of quality (Ramsden, 2003).

In contrast, students' deep learning approach has attracted more interests of academic societies during the recent years due to utilizing students' entire potential in the learning process (Laird, Shoup, & Kuh, 2005). A deep learning deals with *how the students organize the task* (i.e., how to isolate or connect the parts of a structured information) (Ramsden, 2003). A students' deep learning approach seeks fundamental concepts and structures (Hay, 2007), which can be called 'making meaning' based on the constructive theory. This theory represents the ways in which knowledge and meaning have evolved. Such knowledge can be gained using a rational connection between attained experiences and new knowledge by integrating them into novel problems to extract new information (Ditcher, 2001). Besides, students' deep learning elevates comprehension and increases durability of knowledge (Terrón-López, 2016). Through students' deep learning, students try to:

- Analyze new ideas
- Link them to their prior knowledge
- Implement their prior knowledge to solve unfamiliar problems (Vos, 2011)

Based on the definitions, students with a deeper conception of learning have a more pleasant time studying since they have a stronger tendency to use deep approach (Ditcher, 2001). To conclude, a deep learning approach is about both quality and quantity (Ramsden, 2003).

Type of Outcome	Retention Performance	Transfer Performance
Surface Learning	Good	Poor
Deep Learning	Good	Good

Table 2.2: Learning approaches (Mayer, 2011)

Accordingly, the passive learning is correlated with the surface approach. While the active learning puts the students in a way in which the students are led to a deep approach to learn. Since a student's deep learning is generally more desirable than the surface one, it is necessary to study the circumstances in which students use deep learning approach. Student's deep approach occurrence depends on the following phenomena: (Vos, 2011):

(1) Learning approach and teaching context are mutually relevant, so an effective teaching context can derive students to use deep approach to learn.

(2) Student preferences for learning approach can directly influence the student's learning outcomes.

2.2 Teaching Styles

In this section, effective teaching concept from various perspectives is examined. Teaching is how to help people learn (Mayer, 2011). It is *the imparting of knowledge or skill or the giving of instruction* (Westwood, 2008). The instruction itself is *furnishing others with knowledge and information, especially by a systematic method* (Westwood, 2008). Being effective in teaching directly depends on our interpretation of it (J. B. Biggs, 2011). Effective teaching persuades students to employ higher cognitive level activities in order to grasp desired learning outcomes. Hence, students who

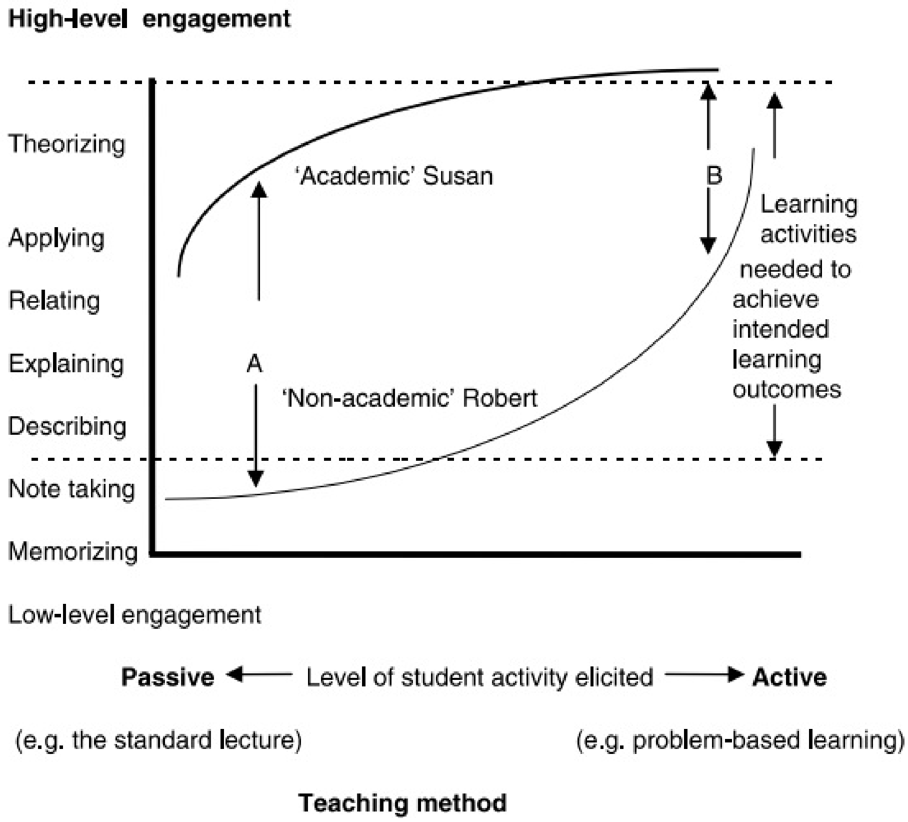

Figure 2.4: Student orientation, teaching method and level of engagement (J. B. Biggs, 2011)

utilize low level cognitive activities end up with using the surface approach. On the other hand, using the higher level cognitive activities leads students to use the deep approach to learn as depicted in Figure 2.4 (J. B. Biggs, 2011).

It is known that due to the massive engineering material, engineering course contents are overloaded with heavy materials in which students are pressured to think about passing the courses, rather than understanding material (Ditcher, 2001). In addition, lectures are not able to transmit knowledge actively due to one sided conversation between one lecturer and students. Lecture-based courses lead students to just follow the instructions blindly which are encouraged to use the surface approach. Intensive wide assessment in lecture-based systems force students to be concentrated on passing the exams rather than focus deeply on concepts to understand underlying meaning (Ditcher, 2001). As it is noted, lecture based courses encourage students to integrate passive learning which is neither desirable for academia nor industry. In view of this, an effective teaching method is necessitated in which the students are guided to the active learning by centering the students in the learning process rather than the lecturer.

To this end, problem based learning (PBL) has arisen in engineering education to close the gap between academia and industry. First, medical education integrated PBL in order to illustrate the application of course content in real life context (Barrows, 1980; Schmidt, 1983). In fact, PBL is a path for students to face the real-life problems encountered in real life where they have to find real world answers (Handbook, 2008). In addition, the use of PBL helps students to enhance their competencies to recall information and to be encouraged by attaining a deeper understanding of concepts. This type of learning derives student toward the improvement of Higher Order Thinking Skills (HOTS) using higher cognitive levels to problem solving and decision making.

PBL tries to duplicate realistic engineering problems and development in academic institutions. PBL intends to teach students to use their knowledge to solve these real problems. This approach is theoretically based on constructive process, metacognition affects, and social and cultural factors (Brodeur, Young, & Blair, 2002). The approach seeks for both more effective technical learning and students' development skills. This approach makes students analyze new concepts using their own experiences and prior knowledge. Hence, the mind itself pursues the students' deep learning approach finding rational links between new knowledge and prior knowledge (Crawley, 2010). The difference between lecture based learning and problem based learning is shown in Figure 2.5.

To prove the effectiveness of PBL, many works have conducted the meta-analysis on different aspects of students' learning outcomes (i.e., Knowledge acquisition, problem solving skills, self-directed learning, group processing, and social and psychological soft skills), yet the results were conflicting(Hung, 2011). Later on, the authors in (Kirschner, Sweller, & Clark, 2006) have opened up a discussion about human cognitive as they think it has been discarded. In (Hmelo-Silver, Duncan, & Chinn, 2007; Schmidt, Loyens, Van Gog, & Paas, 2007), the authors continued the argument by projecting that the human cognitive and problem based learning are interlinked. Accordingly, it is a general agreement by authors that the problem based learning is effective in terms of problem solving skills (Albanese & Mitchell, 1993; Dabbagh & Denisar, 2005; Strobel & Van Barneveld, 2009).

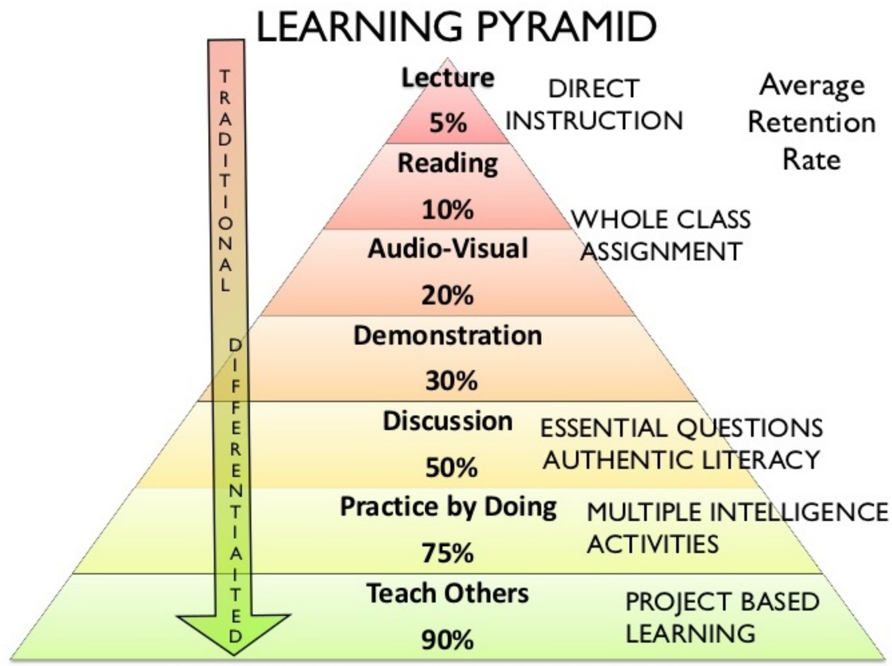

Figure 2.5: Lecture-based vs PBL

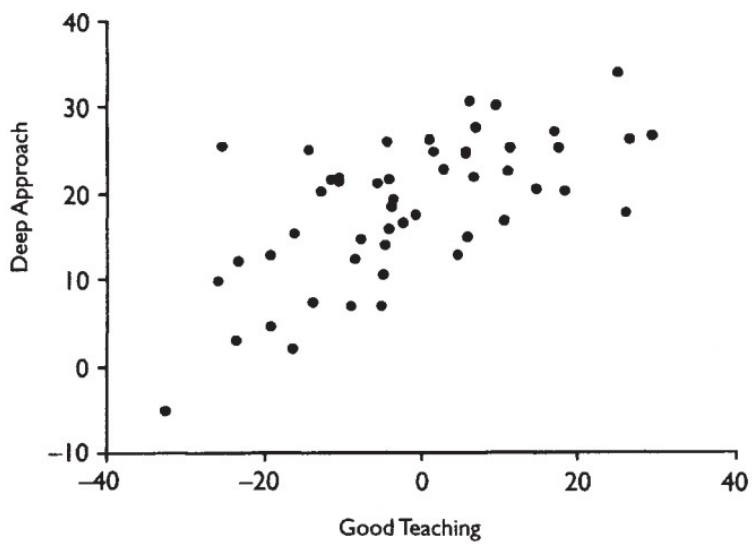

Figure 2.6: Association between deep approach and perceptions of good teaching (Ramsden, 2003)

However, the students' learning approaches have to be measured under a PBL to evaluate the effectiveness of PBL in terms of encouraging students to using deep approach to learn. Metrics for assessing teaching, learning, and instructional effectiveness are not well defined or established (King, 2009). Metrics are important to prove (King, 2009):

(1) Public and student's dollars are being invested wisely with positive results.

(2) Students are receiving the best possible education.

Practical realities of university faculty members include full schedules with many commitments inside and outside the classroom; hence, the methods and metrics for evaluating the effectiveness of learning must be efficient in required time and user friendly (King, 2009). Besides faculty realities, the National Academy of Engineering (NAE) in the US concludes that current assessment methods are heavily dependent on student ratings which may provide only a single dimension of the learning experience (King, 2009). As a result, NAE suggests that effective metrics should include diverse and complementary methods. In the next section, in order to design and develop the students' learning assessment criteria, an introduction regarding the features of an effective design and design methodology is presented. Moreover, Environment Based Design (EBD) as an effective design methodology is introduced which is employed to develop the students' learning assessment criteria which can affect their learning approach.

2.3 Environment Based Design (EBD): Introduction

To achieve a good design, presence of two factors is necessitated a strong design knowledge and a reliable design methodology. Therefore, various design methodology have been proposed such as the systematic design methodology (Pahl & Beitz, 2013), decision-based design (Hazelrigg, 1996), theory of inventive problem solving (TRIZ) (Altshuller, 1984), axiomatic design (Suh, 1990), general design theory (GDT) (Tomiyama & Yoshikawa, 1986), formal design theory (Braha & Maimon, 1998), exploration based design (Smithers & Troxell, 1990), total design (Nagarajan, Passey, Wong, Pritchard, & Nagappan, 2004), adaptable design (Gu, Hashemian, & Nee, 2004), function based design (Bhatta & Goel, 1997), affordance based design (Maier & Fadel, 2009), and design structure matrix (DSM) (Steward, 1981). Although, Tomiyama claimed that most of those methodologies have failed in industry in terms of applicability (Tomiyama & Gu, 2009).

An Environment Based Design (EBD) design methodology proposed by Dr. Zeng (Zeng, 2002, 2003, 2004a, 2004b, 2008; C. Zeng, 1991; P. Zeng, 2004; Y. Zeng, 2008; Y. Zeng & Gu, 1999a, 1999b) is studied and will further be used in this thesis. Environment Based Design is a multi-purpose methodology as specified below :

(1) A prescriptive design model in which designers are led by extraction of customers' requirements along with the design process.

(2) A descriptive design model in which completion of a design process is illustrated.

(3) A derivation from axiomatic design modeling theory (Zeng, 2002).

2.4 Environment Based Design (EBD): Introduction

It is to be noted that the prevalent design methodologies are mostly established based on a design process containing analysis, synthesis and evaluation. The environment based design consists of three major parts as given below:

(1) **Environment analysis:** This part is responsible for seeking key environment phenomena as well as its relationship with each other. The environment components identification is done based on the design problem which is described by the customers. Linguistic analysis is a method to accomplish the environment analysis (Chen & Zeng, 2006).

(2) **Conflict identification:** In this part, conflicts among the environment components are specified.

(3) **Concept generation:** In the last part, solutions are proposed in order to taking care of the identified conflicts.

This iterative process continues until customers' satisfaction is realized in terms of the environment conflicts existence.

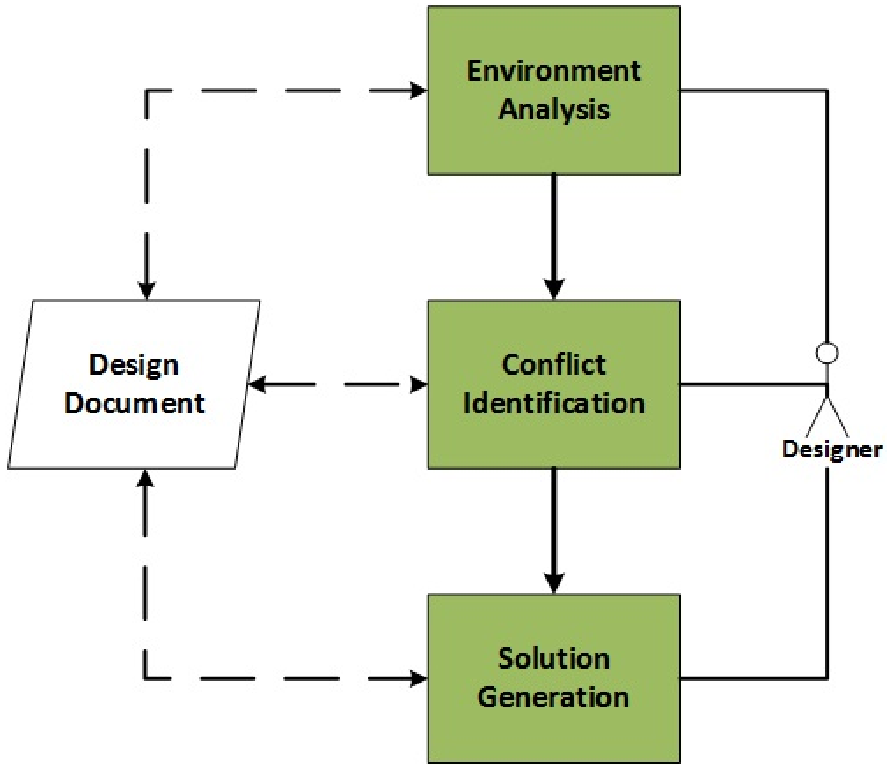

Figure 2.7: EBD process model (Y. Zeng, 2011)

This methodology is resulted from following studies as follows:

- Design is evolved from a recursive process that generates the design solution by meeting with a set of criteria which are determined by the design solutions to be assessed (C. Zeng, 1991).
- Design requirements and product descriptions project the recursive mechanism of design (Y. Zeng & Gu, 1999a, 1999b).
- Structure operation $\bigoplus$ and interaction operation $\bigotimes$ on an object O depict the state of design evolution which is composed of design requirements and product descriptions (Zeng, 2002).

$$\bigoplus E = E \bigcup \left(E \bigotimes E\right) \tag{1}$$

where E is the product environment. Figure 2.8 illustrates the evolution of the design states versus time in the environment based design.

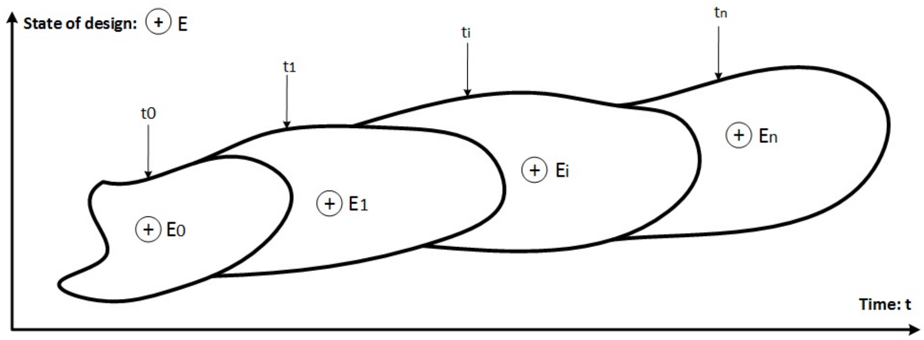

Figure 2.8: The evolution process of design (Zeng, 2004b)

- Along the EBD process, the evolution from $\bigoplus E_i$ to the $\bigoplus E_{i+1}$ is determined by the design equation as given by (Zeng, 2004b):

$$\bigoplus E_{i+1} = K_i^s\Big(K_i^e\big(\bigoplus E_i\big)\Big) \tag{2}$$

where K_i^s and K_i^e are synthesis and evolution operations, respectively.

The evolution and synthesis operators can be considered as forces pulling the state space of design. The evolution operator decreases the state space of design, while the synthesis operator increases it. The design solution is evolved from forces equalization. These operators and their roles are shown in Figure 2.9.

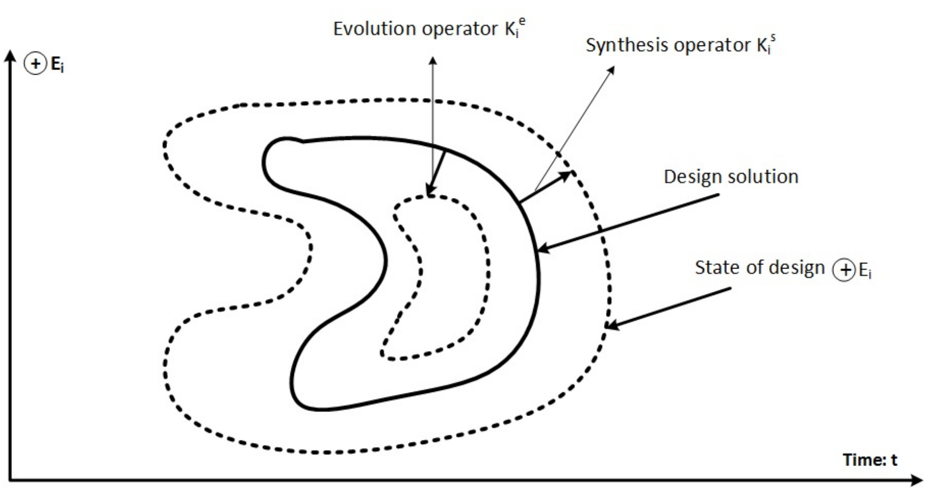

Figure 2.9: State space of design under evolution and synthesis (Zeng, 2004b)

To use EBD, three main steps have to be taken as follows:

- **Environment analysis:** The first step to use EBD is environment analysis. In this step two kinds of question have to be asked. The first is the generic question in which the meaning of design problem is clarified. While, the second one is domain specific questions that imply the design information. To generate those questions, the ROM diagram will be used as a linguistic tool (Zeng, 2004a). Recursive object model has been proposed by (Zeng, 2008). This method is a graphical language which is derived from the axiomatic theory of design modeling in order to represent natural language in engineering to create a clear understanding of design problems and design solutions. ROM utilizes five elements to represent objects, compound objects, constraint relationships, predicate relationships, and connection relationships, as shown in Figure 2.10. The first two types of elements (i.e., object and compound objects) in Figure 2.10 can be used to represent concepts. The other three elements (i.e., constraint, connection, and predicate) can be used to represent different types of relationships between concepts in the domain of student learning.

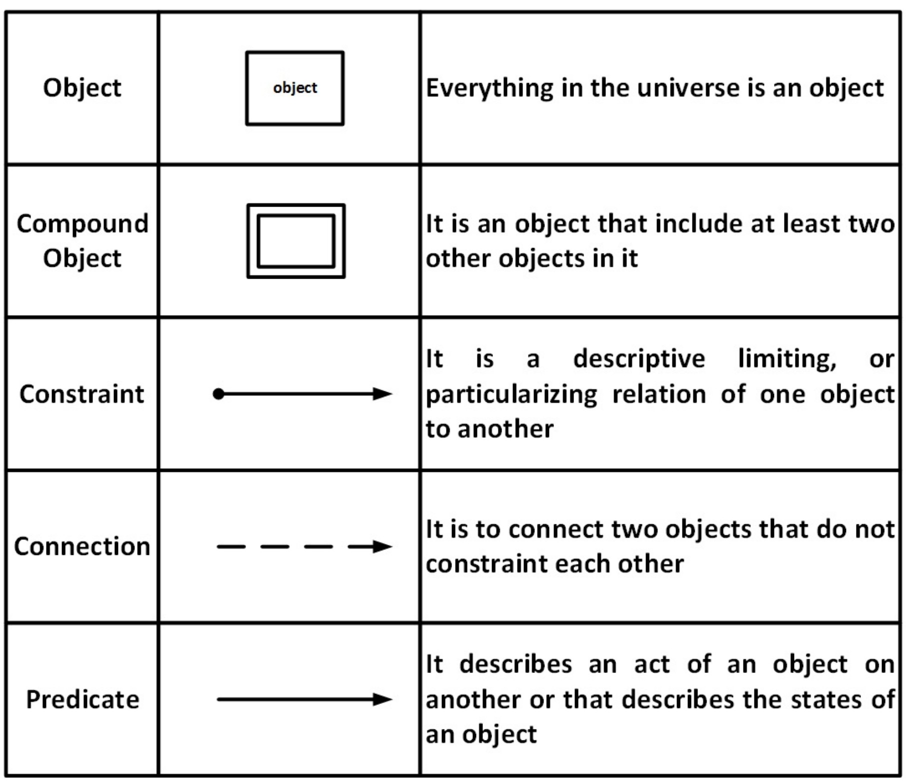

Figure 2.10: ROM elements (Zeng, 2008)

In this step of the environment analysis, two kinds of questions should be asked as follows:

(1) **Generic question:** To generate the generic questions, ROM is used to reach a better comprehension of the design problem as illustrated in Table 2.3.

Step 1	Generate the ROM diagram for the design problem
Step 2	Ask a question using the rules given in Table 2.4 and templates in Table 2.5
Step 3	Find answers to the question
Step 4	Generate the ROM diagram for the answer and merge it back to the original ROM diagram
Step 5	Repeat Step 1-4 until no more questions

Table 2.3: Procedure for generic question asking (Zeng, 2004a)

Rule 1	Before an object can be further defined, the objects constraining them should be further refined
Rule 2	An object with the most undefined constraints should be considered first

Table 2.4: Rules for generic questions (M. Wang & Zeng, 2009)

(2) **Domain question:** The EBD methodology proposed a road map in order to analyze the environment components which are matter to design (Zeng, 2004a). This roadmap aids designer to categorize environment product into two divisions. One partition is product environment based on the product lifecycle whereas the other that categorized natural, built, and human. Figure 2.11 depicts the lifecycle versus environment.

According to Figure 2.11, Table 2.6 offers the flow in which environment components associated to the mattered domain.

- **Conflicts identification:** Based on the ROM diagram, there are three rules which are able to project the possible conflicts as shown in Table 2.7. Those rules will be applied iteratively to identify the whole conflicts.

Templates	Conditions	Question
T1	For a concrete, proper, or abstract noun N	What is N
T2	For a noun naming a quantity Q of an object N, such as height, width, length, capacity, and level	How many / much / long / big / is the Q of N?
T3	For a verb V	How to V? Or Why V?
T4	For a modifier M of a verb V	Why V M?
T5	For an adjective or an adverb A	What do you mean by A?
T6	For a relation R that misses related objects	What (who) R (the given object)? Or (the given object) R what (whom)?

Table 2.5: Templates for generic questions (M. Wang & Zeng, 2009)

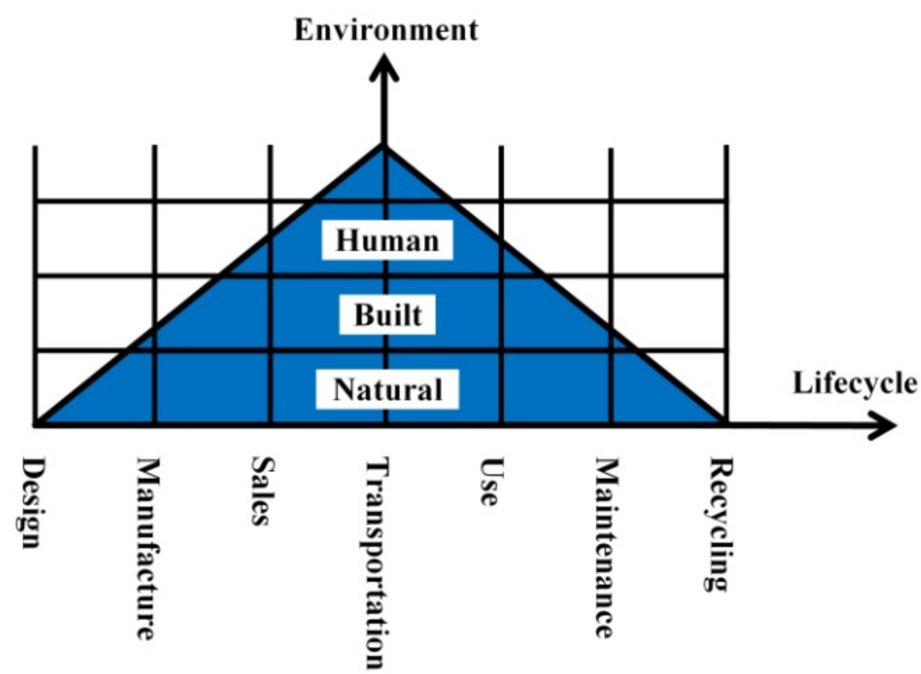

Figure 2.11: Roadmap for domain related environment: an example (Zeng, 2004a)

Step 1	Ask and answer the question: what is the lifecycle of the product to be designed?
Step 2	For each event included in the lifecycle, ask and answer the question: what are the relevant components for natural, built, and human environments for this event?
Step 3	Generate the ROM diagram for each answer and merge them back to the original ROM diagram
Step 4	Apply the procedure for generic question asking

Table 2.6: Procedure for asking domain specific questions (Zeng, 2004a)

Rules	**Description**
Rule 1	If an object has multiple constraints, then potential conflict exists between any pair of constraining objects
Rule 2	If an object has multiple predicate relations from other objects, then potential conflict exists between a pair of those predicate relations
Rule 3	If an object has multiple predicate relations to other objects, then potential conflict exists between a pair of those predicate relations

Table 2.7: Rules for identifying potential conflicts (Zeng, 2004a)

- **Solution generation:** This stage of design is divided into two parts as follows:

  (1) **Atomic design**: It includes the designer's knowledge and experience. Accordingly, an experienced designer can come up with more atomic design than a novice.

  (2) **Recursive solution:** It contains finding answers by decomposing environment components iteratively.

Why EBD? According to (Y. Zeng, 2011), an effective design methodology has to cover the following criteria:

(1) Help designers jump out of the recursive loop between design problems, design knowledge, and design solutions.

(2) Lead to the both routine and creative design naturally.

(3) Help a designer maintain his/her mental stress at an optimal level during the design process.

(4) Include naturally the conditions for the evolution of the design.

EBD has three main activities (i.e., environment analysis, conflict identification, solution generation) which work interdependently and simultaneously together to update the environment to solve the design problem (Y. Zeng, 2011). Hence, EBD helps the designer to jump out of the recursive loop between design requirements, design knowledge, and design solution which are included in the environment (Y. Zeng, 2011). Moreover, as demonstrated in (Y. Zeng & Yao, 2009), following EBD could naturally end up with a creative design which was the second criteria for an effective design methodology. Finally, EBD has met the fourth criteria by its drive which are undesired conflicts between current environment components (Y. Zeng, 2011).

2.5 Introduction of Assessment Methods

Since measurement is a very delicate matter, knowing the measurement meaning is very important. Hence, the definition of measurement is studied from diverse points of view as follows (King, 2009; Loomis, 1993):

- Measurement is "knowing what students know".
- Assessment is about what and how students learn and is designed to capture student's learning outcomes (i.e., knowledge), learning process (i.e., cognitive processes for constructing knowledge), or learning features (i.e., capabilities related to constructing knowledge).
- Measurement is the numerical estimation and expression of the magnitude of one quantity relative to another.
- *Monitoring, documenting and communicating levels of quality and quantity of performance.* (Petrina, 2006).

- The process of gathering information from learners (i.e., obtaining test scores and work samples) (Westwood, 2008).

Different measurement types are used for diverse purposes (e.g., selection, controlling, and meeting the expectations). Thus, different measurements may exist to understand students' knowledge, skills, and affect (King, 2009). NAE indicates that a measurement should be as objective and reliable as possible (King, 2009). Although a requirement of a measurement is to be objective, in reality, faculty evaluation involves judgment implying subjectivity as an integral component of the evaluation process (King, 2009). A fair and unbiased evaluation system should lead any evaluator that examines a set of measurement data to arrive at the same evaluative judgment (King, 2009). To accomplish this goal, subjectivity under control should be sought through consistent application of a predefined set of values in the interpretation of measurement data to arrive at the same evaluative judgment (King, 2009). Assessment methods should consider how well the assessment aligns with the learning goals, specific aspects of teaching and learning intended to be measured, and the intention to use the results (MacIsaac, 2015).

Due to the complexity of students learning outcomes (SLO) and in light of reliability matter, using only one assessment method can be risky. A combination of methods brings a confidence level in which instructor can assure that all aspect of learning have been covered. (SLO) can be measured directly, indirectly, or both. Direct assessment (i.e., tests, essays, presentations, and etc) appeals students to demonstrate their learning. On the other hand, indirect assessment (i.e., surveys and interviews) ask students to get deep on their knowledge ("assessment methods for student learning outcoomes", unkown). There are many known assessment methods so far and some of them are listed in Table 2.8.

However, the two predominant assessment purposes are for "*summative grading*" and "*formative feedback*" (Mayer, 2011), which are representative of two major types of assessment as follows:

(1) **Summative:** This type of assessment (i.e., Mid-term Exam, Final Exam, etc) are tools and methods that extract and monitor students' progress through the course or program based on standards and benchmarks at the end of semester or unit by grading them (Handbook, 2008; Petrina, 2006). Its goal is to determine whether students have learned what they must

Method	Description	Direct or Indirect Data
Capstone Project	A capstone project or course integrates knowledge, concepts, and skills that students are to have acquired during the course of their study. Capstones provide a means to assess student achievement across a discipline	Direct
Course Evaluation Survey	Course evaluations assess student experience and satisfaction with an individual course and are generally administered at or near the end of the semester. They provide the faculty, department, and institution with student perceptions of the classroom aspect of their educational experience	Indirect
Portfolio	Students work is collected throughout a program which is assessed by faculty using a common scoring guide/rubric. Portfolios may contain research papers, reports, tests, exams, case studies, video, personal essays, journals, self-evaluations, exercises, etc	Direct
Pre & Post Tests	Typically an exam is administered at the beginning and at the end of a course or program in order to determine the progress of student learning	Direct
Embedded Techniques	Embedded assessment techniques utilize existing student course work as both a grading instrument as well as data in the assessment of SLO	Direct
Rubrics/ Scoring Guides	Rubrics/scoring guides outline identified criteria for successfully completing an assignment and establish levels for meeting the criteria. They can be used to score everything from essays to performances	Direct
Focus Groups	A series of structured discussions with students who are asked a series of open-ended questions designed to collect data about beliefs, attitudes, and experiences	Indirect

Table 2.8: Assessment methods adopted from ("assessment methods for student learning outcoomes", unkown)

have learned by using grades and final marks which makes student anticipate for their grades. (J. B. Biggs, 2011). The summative assessment focuses on improvement and application of instruments in order to assess what students have acquired by the assessment time (Council, 2013)

(2) **Formative:** It is a progressive type of assessment which is not a graded measurement that is used to round up learned knowledge and concepts (Handbook, 2008). In contrast, it is used to get feedback from both student and instructor in order to communicate, monitor, and develop the learning process throughout the program (J. B. Biggs, 2011; Petrina, 2006). (Black & Wiliam, 1998) approves the formative assessment as *all those activities undertaken by teachers and/or by their students that provide information to be used as feedback to modify the teaching and learning activities in which they are engaged* (p. 7). (Erickson, 2007) describes it as *the continual 'taking stock' that teachers do by paying firsthand observational attention to students during the ongoing course of instruction—careful attention focused on specific aspects of a student's developing understanding*(p. 187). It is better to describe formative assessment by its cause which is able to help improve the learning style and the shape of students during the learning process, rather than see it as an instrument or task (Trumbull & Lash, 2013).

This work focuses on the formative assessment rather than the summative one, since the formative assessment is not a graded quiz based upon memorization but rather based on how the student actually understood and acquired the material. In addition, the formative assessment encourages students to think in order to enhance their problem solving skills as well as helping instructors to understand weaknesses with learning (MacIsaac, 2015; Mayer, 2011). Formative assessments also provide vital information for students in which they will be able to meter their own learning and regularize their own way of learning.

Formative assessment is used to get feedback during the learning process to understand underlying causes of how learning happens. Feedback is *information provided by an agent (e.g., teacher, peer, parent, the assessment itself) regarding aspects of one's performance or understanding* (Hattie & Timperley, 2007) (p. 81). Formative feedback is a key to improve teaching and learning quality by supplying data regarding the gap between students' current knowledge and sought knowledge. Furthermore, feedback assists the students to comprehend the learning goal, how fast they are moving toward this goal, and what exactly they need to employ in order to attain the goal (J. B. Biggs, 2011; Trumbull & Lash, 2013). There are several types of assessment methods, including: conceptual understanding (e.g., concept inventories, and concept Tests) with pre-test and post-test, student writing (e.g., assignments, reading reflections, and cases), affective assessment with pre-test and post-tests (e.g., Geoscience Affective Research NETwork (GARNET)), assessment of group work (e.g., two-stage exams to evaluate individual and group learning), and others (e.g., exam questions based on daily learning objectives, upside-down Pedagogies (SCALE-UP), and Meta-cognitive Activities Inventory (MCAI)) (Council, 2001, 2012; MacIsaac, 2015).

To design an effective assessment method, a comprehension of principals in designing assessment method can be valuable to teachers in terms of achieving good quality information from students (Trumbull & Lash, 2013). Assessment triangle is a very useful heuristic to design an effective assessment which can extract high quality information from students. These elements are (Trumbull & Lash, 2013):

(1) **Model of student cognition:** Explains how students abilities can evolve in an academic domain and how they set out their knowledge at the various levels of development.

(2) **Observations:** include tasks in which student performance is graded and evaluated in order to collect data as evidence of learning.

(3) **Interpretation:** drawing of a conclusion from data that has been gathered.

A fourth element in formative assessment has to be considered: the interpretation of assessments performance should be effectively translated into instructional decisions and actions (Trumbull & Lash, 2013).

Evidence Centered Design (ECD) has been introduced by (Almond, Steinberg, & Mislevy, 2003), and it is an approach which constructs plain and clear connections between the elements of assessment triangle by providing a mechanism to construct an accurate assessment. According to ECD, indispensable evidence has to be pinpointed in order to make rational decisions in terms of determined features of student's learning. Hence, all students have this opportunity to present their learning components (i.e., knowledge, skill, and affect) (Trumbull & Lash, 2013).

(Black & Wiliam, 1998) has reviewed 681 publications associated with formative assessments since it has been highly praised for its claimed positive impact on student learning. They also came up with idea that *attention to formative assessment can lead to significant learning gains and having empty negative impact on student learning so far.*

In theory, the most ideal scenario to assess students' learning is to break down the population during time into different cohorts. The cohorts of students are exposed to different learning approaches with the same expected learning outcomes. A research strategy to deal with different cohorts of students that suggesting four student's groups, is presented in Figure 2.12.

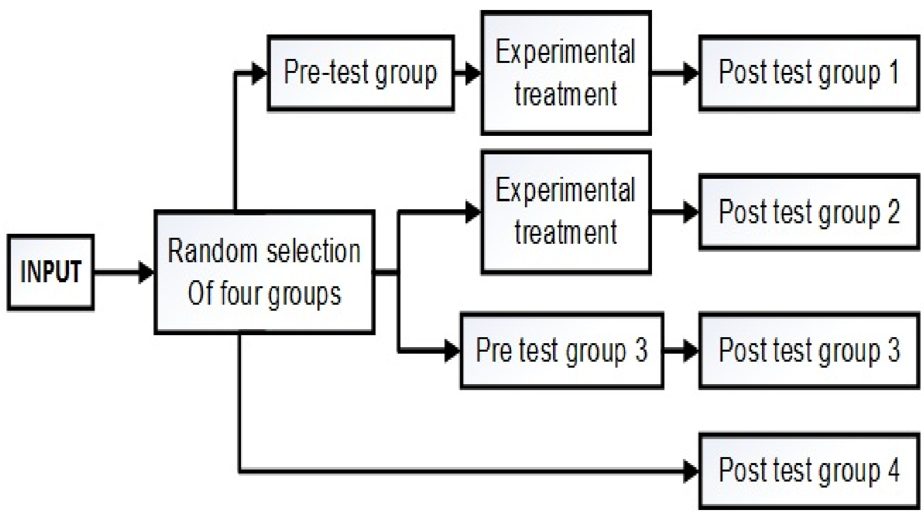

Figure 2.12: A research strategy for dealing with groups (Entwistle, 2002)

The first group refers to students doing a pre-test (e.g., diagnostics assessment) followed by an experimental treatment in an instructional method and one post-test assessment. The second group excludes a pre-test, but students are exposed to an experimental treatment and a post-test assessment. The third group includes students conducting a pre-test followed by no intentional changes in the instruction and a post-test assessment. The fourth group refers to the scenario where students are exposed to the regular instructional method and only one post-test assessment is conducted.

The research strategy described in Figure 2.12 can be used to differentiate changes in student cohorts cross-regionally and longitudinally year after year. The research strategy in Figure 2.12 serves the following purposes: (MacIsaac, 2015):

(1) Indicate how well reforms are working and reveal areas for future adjustments.

(2) Convince your organization/department/colleagues/self about the instruction effectiveness.

(3) Provide the students with the evidence to explain why they are asked to do certain things and their benefits from the assessment.

2.6 Summary

In this chapter, the new requirements which industries asking for from graduated engineers have been discussed. As noted, industries are looking for graduated engineers with both technical skills and professional skills. However, the traditional lecture-based system has failed to deliver the desired attributes for graduated engineers.

In order to tackle this problem, definitions of teaching and learning as well as their methods and approaches have been presented. Among the students' approaches to learn, a deep learning approach has been selected as an effective student's learning approach. Due to the failure of lecture-based system to encourage students to use deep approach, a Problem Based Learning (PBL) teaching method has been proposed to encourage students to use deep learning approach.

However, the effectiveness of students' learning has to be assessed in order to qualify the teaching context and the assessment methods. To do so, an Environment Based Design methodology has been introduced to design the assessment criteria.

To measure the assessment criteria, measurement has been identified from different points of view. Moreover, various types of measurement methods has been introduced and discussed (i.e., formative, summative, direct, indirect, qualitative, quantitative).

Chapter 3

Developing Assessment Criteria by Using Environment Based Design (EBD)

As clarified in Chapter 2, between the learning approaches (i.e., surface and deep), the deep learning approach is the desirable one. However, achieving the students' deep learning always has been issued. Therefore, the designer has to take EBD steps in order to elicit the design requirements related to the measuring the effectiveness of student learning. Based on the problem definition in literature review, the problem statement can be written as follows:

- **Design problem 1:** Design a teaching context to encourage the students to use the deep approach to learn
- **Design problem 2:** To design a measurement tool to measure the students' learning style

Now, in order to analysis the design problems, an eight steps process is conducted as follows:

(1) **Step 1:** Draw the ROM diagram based on the identified design problems shown in Figure 3.1 and Figure 3.2.

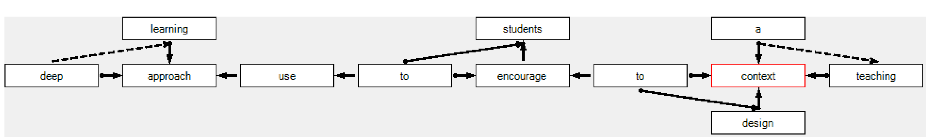

Figure 3.1: ROM diagram for problem 1

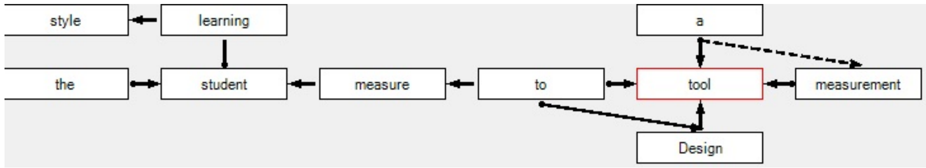

Figure 3.2: ROM diagram for problem 2

(2) **Step 2:** In this step, the generic questions are generated based on the ROM diagram. The designer creates questions while looking up to the rule 1 and rule 2 explained in Table 2.4. In addition, designer generates questions based on the templates provided in Table 2.5.

For design problem 1, considering rule 1 and rule 2, the teaching context and learning approach have to be clarified first. Q1 and Q2 are generated first based on the T1 provided in the Table 2.5. Q3 is asked based on T2 and Q4 and Q5 regarding to the T3. Moreover, more question/s can be generated. Q5 brought up to more clarification.

Question	**Description**
Q1-1	What is the teaching context?
Q2-1	What is the desirable learning approach?
Q3-1	How many learning approach are there for students?
Q4-1	How can a teaching context be important?
Q5-1	Why does designer want to use teaching context in design?

Table 3.1: Step2 questions for problem 1

Question	Description
Q1-2	What is the student's learning style?
Q2-2	What is a measurement tool?
Q3-2	How many learning style are there for students?
Q4-2	How a learning style can be important?
Q5-2	Why does designer want to use learning style in design?
Q6-2	Why does designer want to use measurement tool in design?

Table 3.2: Step2 questions for problem 1

(3) **Step 3:** In this step, the questions provided in Table 3.1 and Table 3.2 are answered. To do so, designer should use the dictionary, their existing knowledge, browsing on the internet, or by asking the others. The answered shown in Table 3.3 and Table 3.4.

Answer	Description
A1-1	Teaching context refers to the framework in which the course content is taught
A2-1	Learning approach is the way that students process the knowledge
A3-1	The most important identified students' learning approaches are deep approach and surface approach
A4-1	Teaching context affects the students' cognitive domains which are consisted of knowledge and skills
A5-1	The teaching context can determine the learning approach. A proper teaching context can be eventuated to a desirable learning approach

Table 3.3: Step3 answers for problem 1

(4) **Step 4:** steps 1 to 4 should be repeated until no more questions can be asked. Similarly, all answers should go through steps 1 to 4.

Answer	Description
A1-2	Students' learning style refers to the students' preference for the learning approach
A2-2	The measurement is defined as a fundamental procedure to elicit reliable information. Evidently, the tool which is used to accomplish that procedure is referred to measurement tool
A3-2	Generally, the student's learning style can be categorized as surface style and deep style
A4-2	Learning style affects the student's affective domains which are related to the student's feeling and preference
A5-2	The Learning style can pinpoint the learning approach. A deep learning style encourages the student to use deep approach. In contrast, a surface learning style leads the student to use surface learning approach
A6-2	The measurement tool enables designer to measure the learning approach criteria

Table 3.4: Step3 answers for problem 2

The answers related to the design problem 1 are analyzed as follows:

- **A1-1:** Teaching context refers to the framework in which the course content is taught.

  The ROM diagram shown in Figure 3.3.

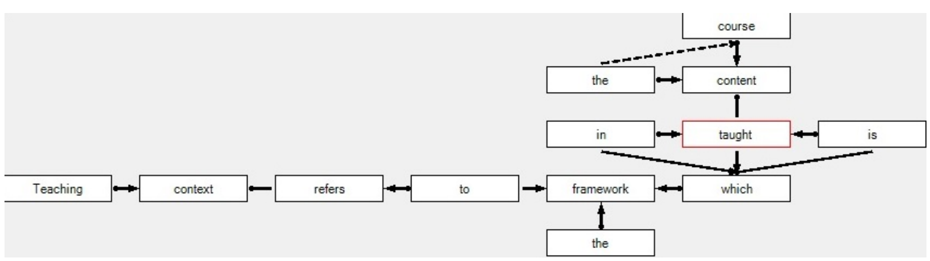

Figure 3.3: ROM diagram for answer 1 of problem 1

- **A2-1:** Learning approach is the way that students process the knowledge.

  The pertinent ROM diagram shown in Figure 3.8.

- **A3-1:** There are a few identified learning approach so far. The most important ones are deep approach and surface approach.

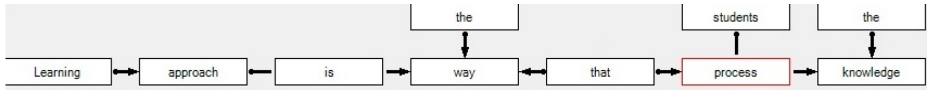

Figure 3.4: ROM diagram for answer 2 of problem 1

The related ROM diagram shown in Figure 3.5.

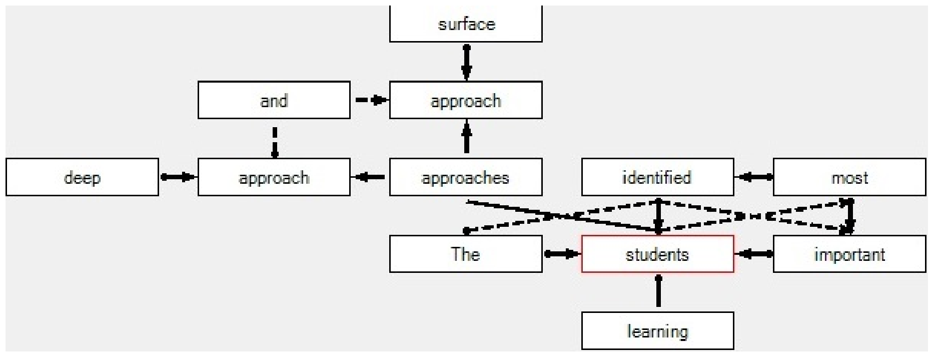

Figure 3.5: ROM diagram for answer 3 of problem 1

- **A4-1:** Teaching context affects the student's cognitive domains which are consisted of knowledge and skills.

  The corresponding ROM diagram presented in Figure 3.6.

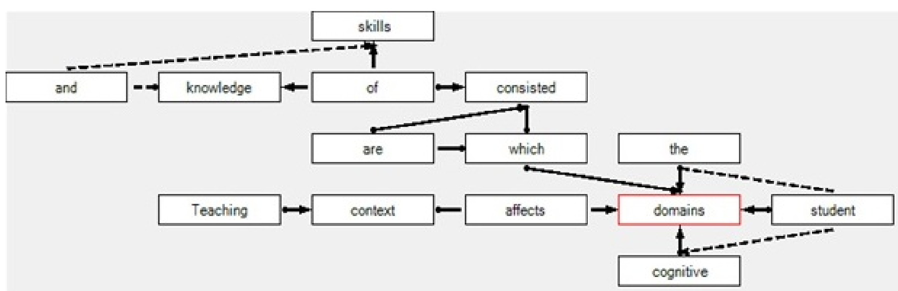

Figure 3.6: ROM diagram for answer 4 of problem 1

- **A5-1:** The teaching context can determine the learning approach. A proper teaching context can be eventuated to a desirable learning approach.

  The relevant ROM diagram depicted in Figure 3.7.

Correspondingly, the answers related to the problem 2 are studied as follows:

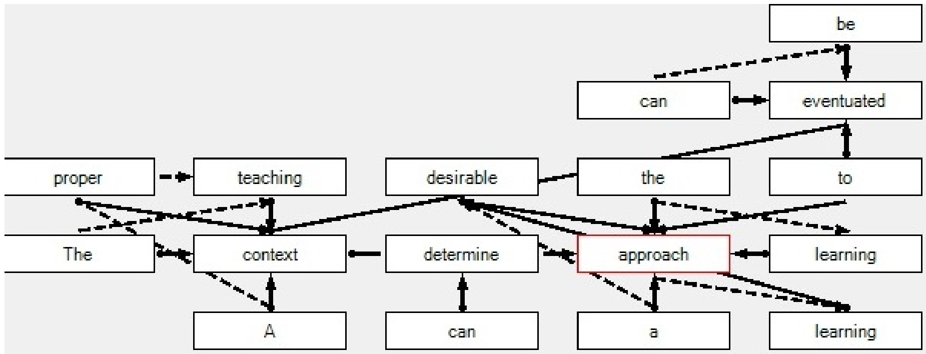

Figure 3.7: ROM diagram for answer 5 of problem 1

- **A1-2:** Student's learning style refers to the student's preference for the learning approach.

  The ROM diagram correspond to the answer 1 shown if Figure 3.8.

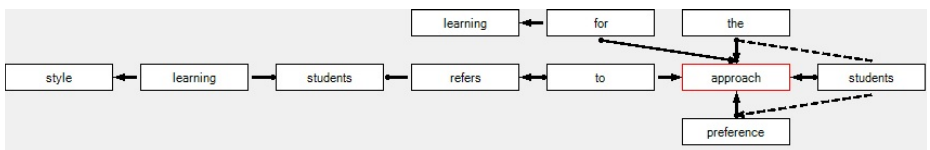

Figure 3.8: ROM diagram for answer 1 of problem 2

- **A2-2:** The measurement is defined as a fundamental procedure to elicit reliable information. Evidently, the tool which is used to accomplish that procedure is referred to measurement tool.

  The related ROM shown in Figure 3.9.

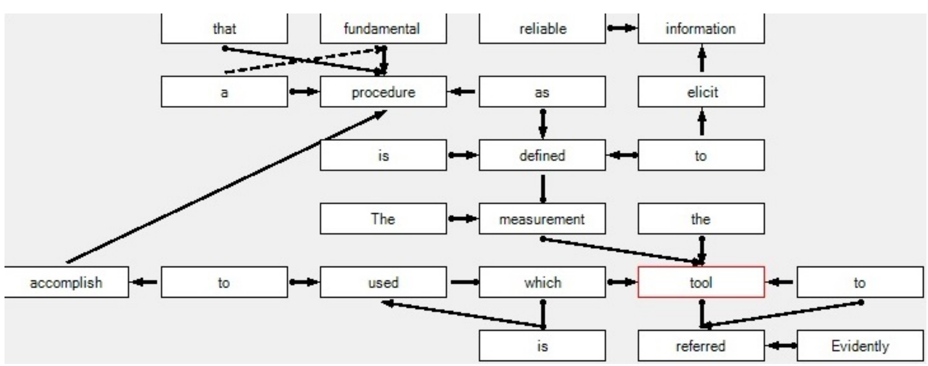

Figure 3.9: ROM diagram for answer 2 of problem 2

- **A3-2:** Generally, the student's learning style can be categorized as surface style and deep style.

The ROM diagram correspond to the answer 3 shown in Figure 3.10.

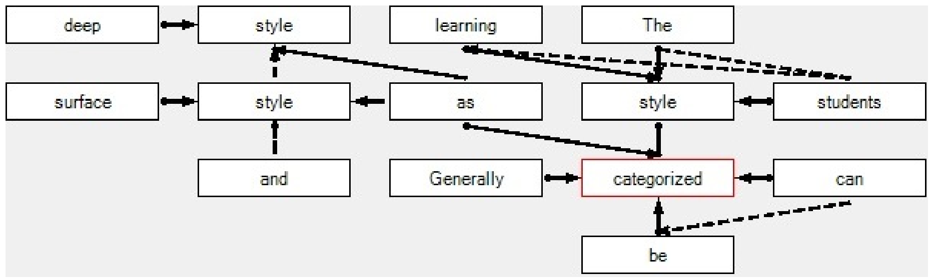

Figure 3.10: ROM diagram for answer 3 of problem 2

- **A4-2:** Learning style affects the student's affective domains which are related to the student's feeling and preference.

  The relevant ROM diagram depicted in Figure 3.11.

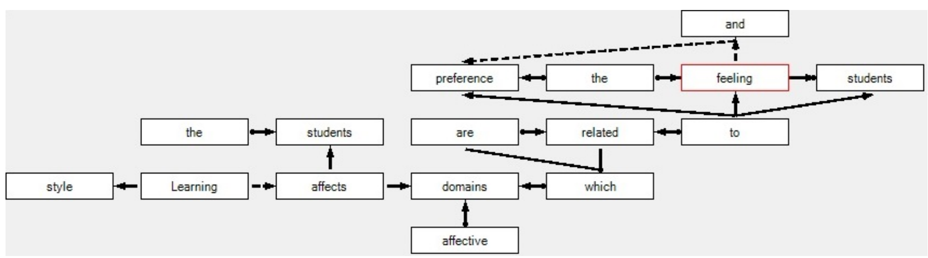

Figure 3.11: ROM diagram for answer 4 of problem 2

- **A5-2:** The learning style can pinpoint the learning approach. A deep learning style encourages the student to use deep approach. In contrast, a surface learning style leads the student to use surface learning approach.

  The related ROM diagram shown in Figure 3.12.

- **A6-2:** The measurement tool enables designer to measure learning approach criteria. The pertained ROM diagram shown in Figure 3.13.

In these scenarios, no more questions need to be asked. The final ROM diagram for problem 1 consists of all ROM diagrams (i.e., Figure 3.9, Figure 3.10, Figure 3.11, Figure 3.12, and Figure 3.13) shown in Figure 3.14. Similarly, the final ROM diagram for problem 2 composed

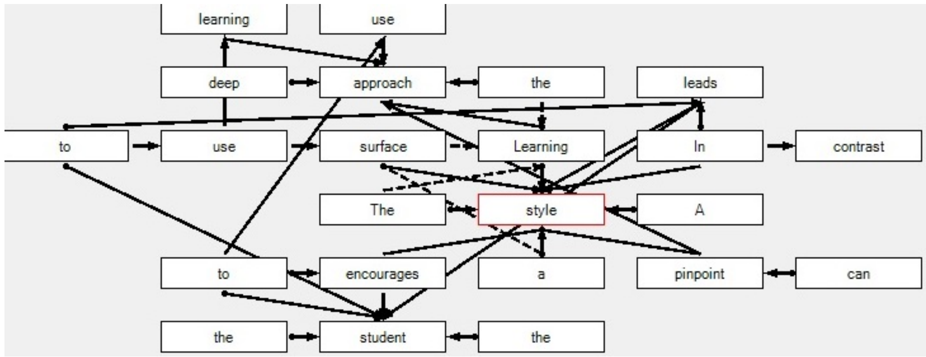

Figure 3.12: ROM diagram for answer 5 of problem 2

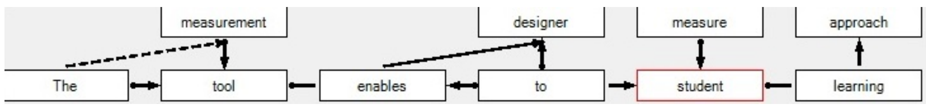

Figure 3.13: ROM diagram for answer 6 of problem 2

of all related answers (i.e., Figure 3.14, Figure 3.15, Figure 3.16, Figure 3.17, Figure 3.18, and Figure 3.19) shown in Figure 3.15.

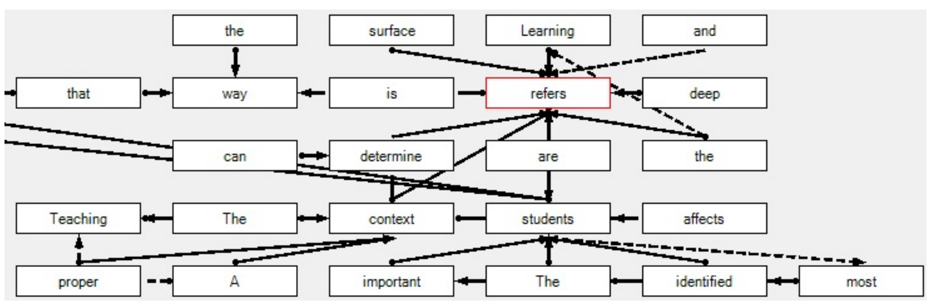

Figure 3.14: Merged ROM diagram step 4 for problem 1

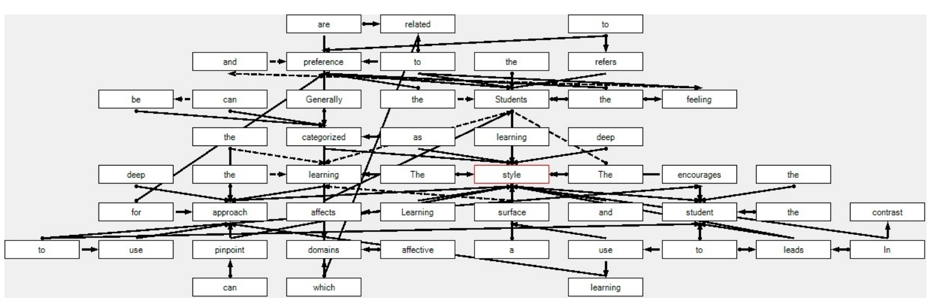

Figure 3.15: Merged ROM diagram step 4 for problem 2

(5) **Step 5:** In this step, domain specific questions should be asked based on the steps which have been illustrated in Table 2.6. The questions related to the problem 1 and problem 2 are shown

in Table 3.5 and Table 3.6 respectively.

Through this analysis, environment components based on nature, built, and human are identified as follows:

(a) **Built:** It contains classroom and teaching context as built.

(b) **Human:** The instructor and the students.

(c) **Natural:** The nature consists of air, earth, student learning, student's learning style, and etc.

Question	Description
Q6-1	What is the lifecycle of the design a teaching context?
Q7-1	What standards should be considered in designing teaching context?
Q8-1	Who are involved in the implementation of a teaching context?

Table 3.5: Domain questions for problem 1

Question	Description
Q7-2	What is the lifecycle of the design student learning preference measurement tool?
Q8-2	What standards should be considered in student learning preference measurement tool design?
Q9-2	Who are involved in the implementation of a student learning preference measurement tool?

Table 3.6: Domain questions for problem 2

(6) **Step 6:** The domain questions generated in step 5 are answered that is depicted in Table 3.7 and Table 3.8.

(7) **Step 7:** Repeat step 1 to 7 in this step to ensure that no more domain questions left to ask.

The domain answers should analyze by ROM diagram and get merged to the ROM diagram

Answer	Description
A6-1	The lifecycle of the teaching context design includes generating problem, design, data gathering, and analyze data
A7-1	The teaching context has to meet the essential educational standards like ABET accreditation
A8-1	The instructor and the students are involved in using the teaching context

Table 3.7: Domain answers related to problem 1

Answer	Description
A7-2	The lifecycle of the design a student learning preference measurement tool includes problem generating, design, data gathering, and analyze data
A8-2	The student learning preference measurement tool has to meet the five essential characteristics of quality educational assessments (i.e., content validity, reliability, fairness, student engagement and motivation, and consequential relevance)
A9-2	The instructor and the students are involved in using the students' learning preference measurement tool

Table 3.8: Domain answers related to problem 2

step 4. A part of the Final ROM diagram shown in Figure 3.16 for problem 1 and Figure 3.17 for problem 2.

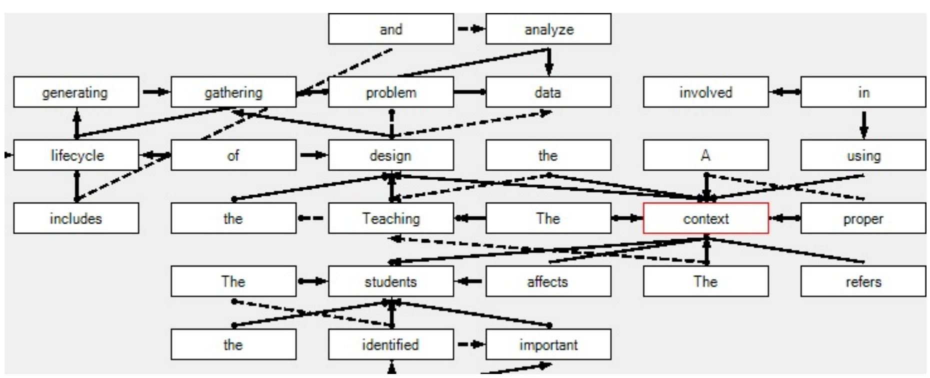

Figure 3.16: A part of whole ROM diagram for problem 1

(8) **Step 8:** By analyzing the ROM diagrams and translate them into the natural language, the

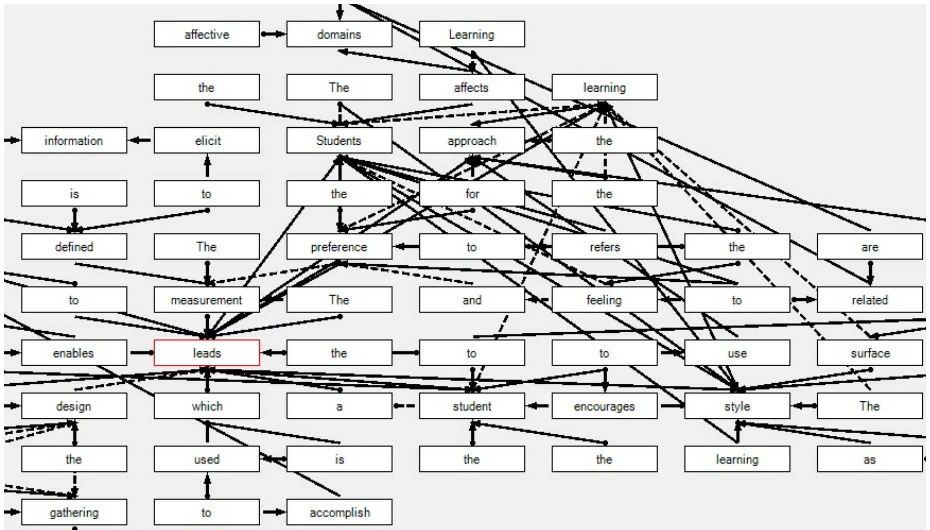

Figure 3.17: A part of whole ROM diagram for problem 2

output of design can be updated along with the design requirements elicitation.

Two design tasks have been performed as follows:

• Design a teaching context to encourage students to use deep approach to learn.

• Design a measurement tool to scale students' learning style.

Teaching context refers to the framework in which the course content is taught. A learning approach is the way that students process the knowledge. There are a few identified learning approach so far. The most important ones are students' deep learning approach and students' surface learning approach. Teaching context affects the student's cognitive domains which are consisted of knowledge and skills. In addition, the teaching context can determine the learning approach. A proper teaching context can be eventuated to a desirable learning approach. Therefore, cognitive domains of learning (knowledge and skills) are the design requirements which have to be measured in order to evaluate the teaching context as well as the student learning approach. Moreover, a flying house design session is introduced in Chapter 4 as a PBL teaching context.

On the other hand, a student's learning style refers to the student's preference for the learning approach. The measurement is defined as a fundamental procedure to elicit reliable information. Evidently, the tool which is used to accomplish that procedure is called to measurement tool. Generally, the student's learning style can be categorized as surface style and deep style. Learning style affects the student's affective domains which are related to the student's feeling and preference. The learning style can pinpoint the learning approach. A deep learning style encourages the student to use deep approach to learn. In contrast, a surface learning style leads the student to use surface learning approach. Hence, besides the cognitive domains, affective domains (student learning preference and attitude) are included in the design requirements.

Based on the ROM diagram, measurement tools are required to assess the design requirements (i.e., knowledge, skills, and affect). In Chapter 4, assessment methods are introduced and explained based on their usage and suitability.

The lifecycle of the teaching context design and the student learning preference measurement tool design includes generating problem, design, data gathering, and analyze data. Moreover, the instructor and the students are involved in using the teaching context and the student learning preference measurement tool. The teaching context has to meet the essential educational standards like ABET accreditation and the student learning preference measurement tool design has to meet the five essential characteristics of quality educational assessments (i.e., content validity, reliability, fairness, student engagement and motivation, and consequential relevance).

Elicited Design Requirements:

• A proper teaching context can be eventuated to a desirable learning approach.

• Teaching context affects the students' cognitive domains which are consisted of knowledge and skills.

• Learning style affects the students' affective domains which are related to the students feeling and preference.

• A deep learning style encourages the students to use deep approach.

Knowledge: Knowledge level in design fields such as design science, design process, and EBD.

Skills: Students' expertness in solving design problem for instance creative design and design thinking.

Affect: It is referred to the students' learning preference in a design session.

In Figure 3.18 the generic questions process illustrated. Moreover, Figure 3.19 explains the domain specific questions generation. The whole process described by Figure 3.20.

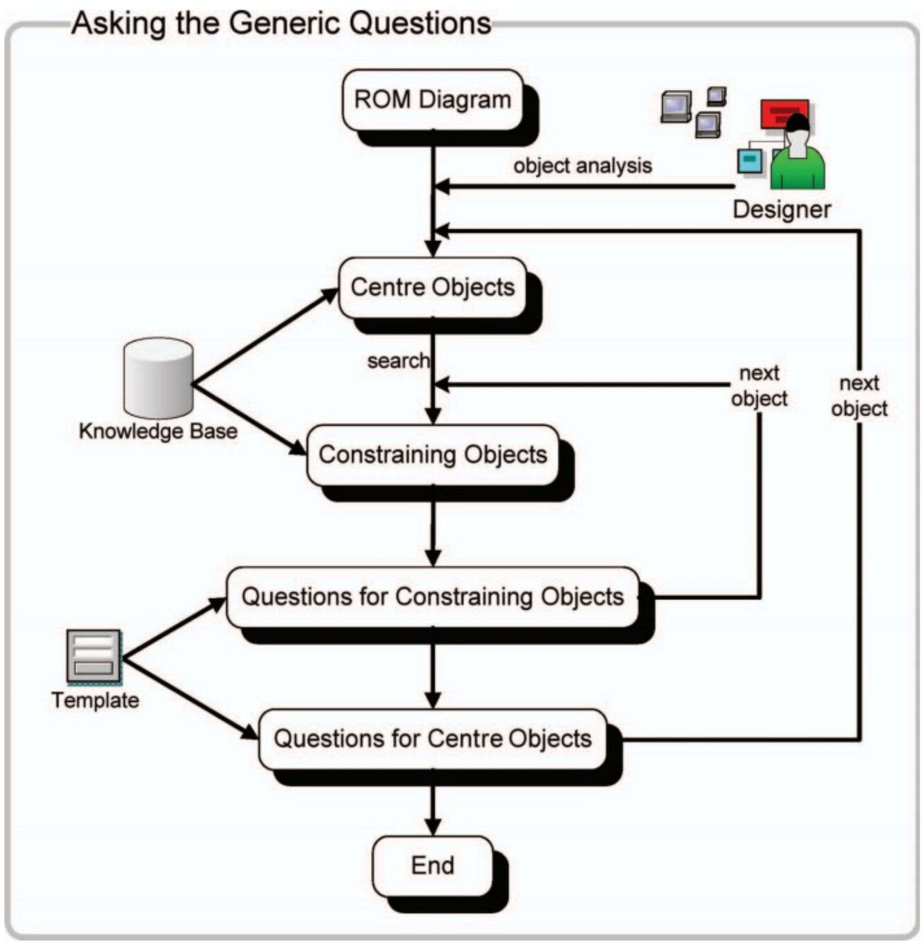

Figure 3.18: Asking the generic questions (Z. Wang, 2009)

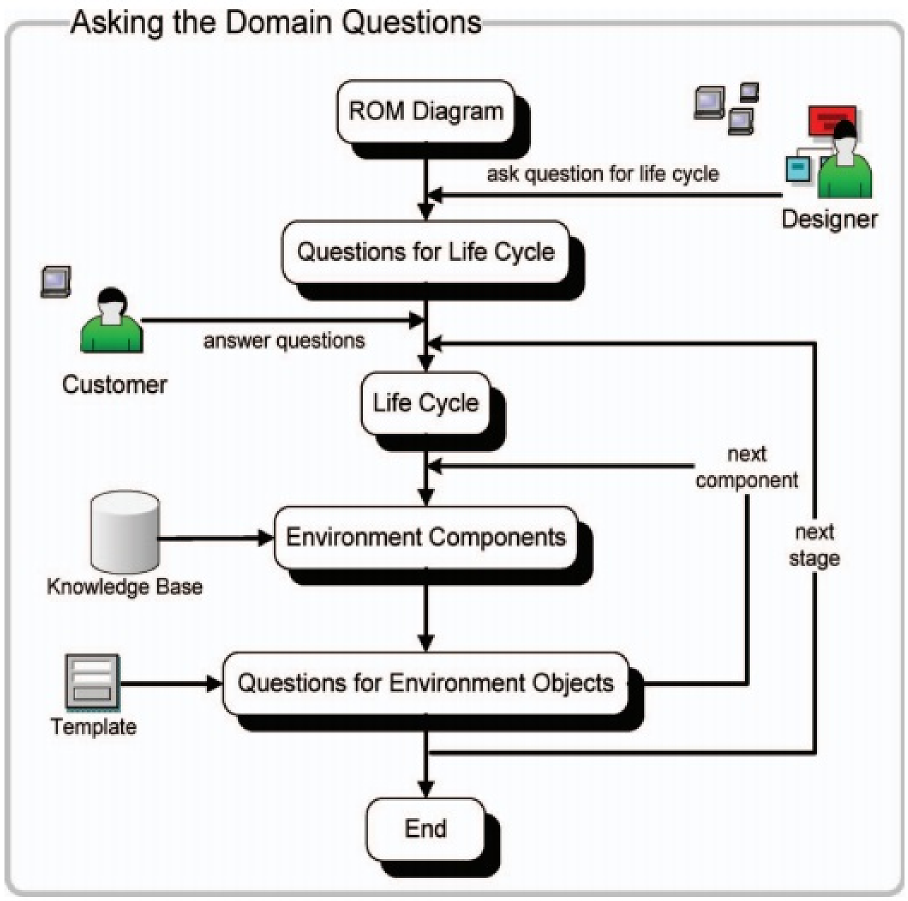

Figure 3.19: Asking the domain specific questions (Z. Wang, 2009)

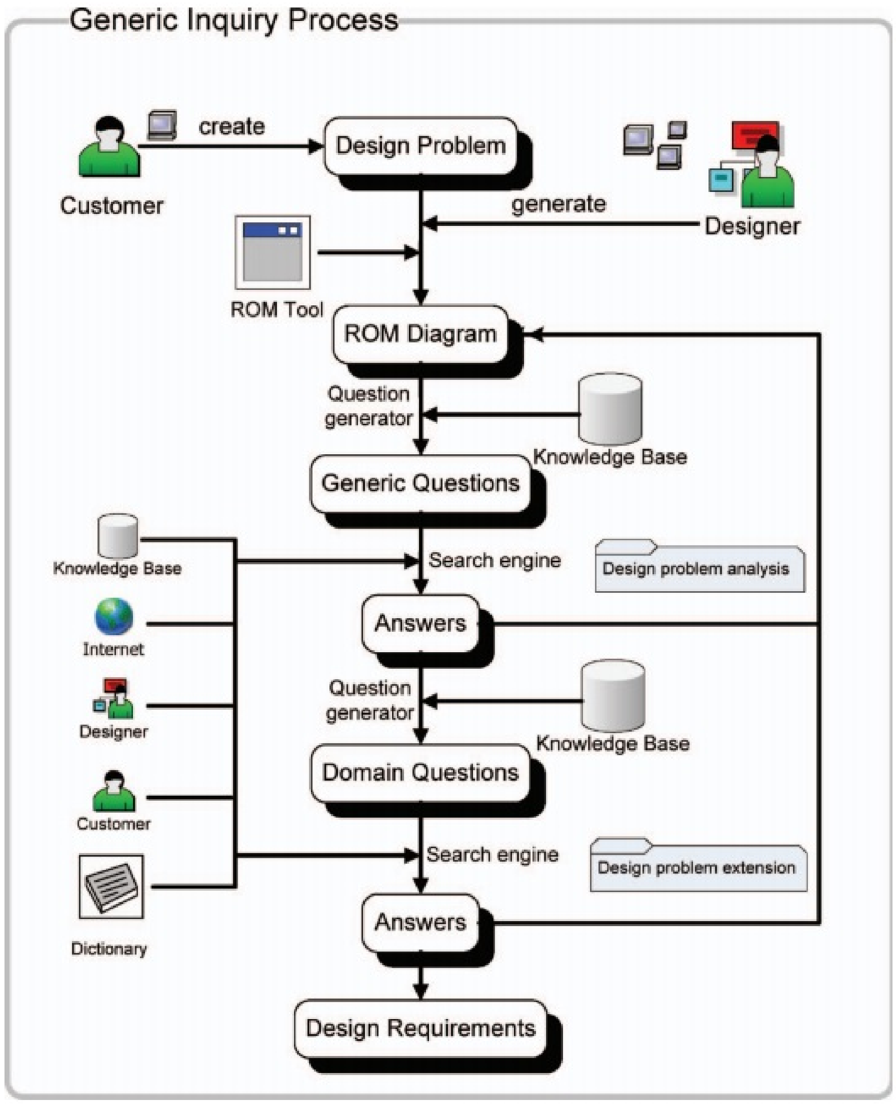

Figure 3.20: Generic inquiry process for requirements elicitation (Z. Wang, 2009)

3.1 Validation of Assessment Criteria by Using Bloom's Taxonomy

To have a good understanding of taxonomy, it needs to be defined as a word. Taxonomy means "*Classification*". It is used to classify things into categories. The main purpose of classification is to facilitate communication and understanding of how things should be well-organized. The idea of Bloom's taxonomy was generated from a meeting in 1948 by the American Psychological Association Convention in Boston. Moreover, its purpose is to classify the educational objectives into different level of complexity. (Anderson, 2001; Bloom, 1956). The bloom's taxonomy has been designed to cover three domains of learning as follows:

(1) **Cognitive:** This domain contains objectives which takes into account the knowledge and enhancement of intellectual abilities and skills (Bloom, 1956). *Gestalt psychology addresses changes in perception as the key to learning in problem solving. Specifically forming an accurate representation of the problem indicates the nature of the solution.* (p. 188) (Gredler, 1997). It can be considered as the most important part of educational domain (Handbook, 2008). Table 3.9 gives the cognitive domain based on Bloom's Taxonomy. Similarly, Figure 3.21 illustrates the cognitive levels from the lowest order thinking skills to highest one.

Knowledge: The remembering of learned material. This involves the recall of a range of material, from specific facts to complete theories, in an appropriate form	Recognize, identify, notice, distinguish, aware, detect, locate, select, compare, adjust, listen
Comprehension: The ability to grasp meanings and understand. This may be demonstrated by translating from one to another (words to numbers), by interpreting material (explaining or summarizing), and by estimating future trends (predicting consequences or effects)	Identify, describe, compute, associate, position, sort, acknowledge, express, respond, select, convert
Application: The ability to use knowledge in new and concrete situations. This may involve the application of concepts, laws, methods, procedures, principles, and theories	Change, demonstrate, discover, modify, operate, predict, prepare, solve
Analysis: The ability to break down knowledge into component parts so that its original structure may be understood. This may include the identification of parts, analysis of the relationship between parts, and the recognition of organizational principles involved	Diagram, discriminate, distinguish, infer, outline, relate, separate
Synthesis: The ability to combine parts to form a new, original entity. This may involve the production of a unique communication (theme or speech), a plan of operations (intervention or management structure), or set of concrete relations	Categorize, combine, create, devise, design, generate, plan, reconstruct, rearrange, revise, explain
Evaluation: The ability to judge the value of knowledge, material or designs. The judgment is based on definite criteria. These may be internal criteria (organization) or eternal criteria (ethics, relevance)	Appraise, control, compare, criticise, justify, interpret, discriminate, contrast

Table 3.9: Cognitive domain (Bloom, 1956)

(2) **Affective:** This domain addresses the changes in attitudes, emotions, appreciations, interests, preferences,and values (Bloom, 1956; Petrina, 2006). Table 3.10 describes affective domain in details.

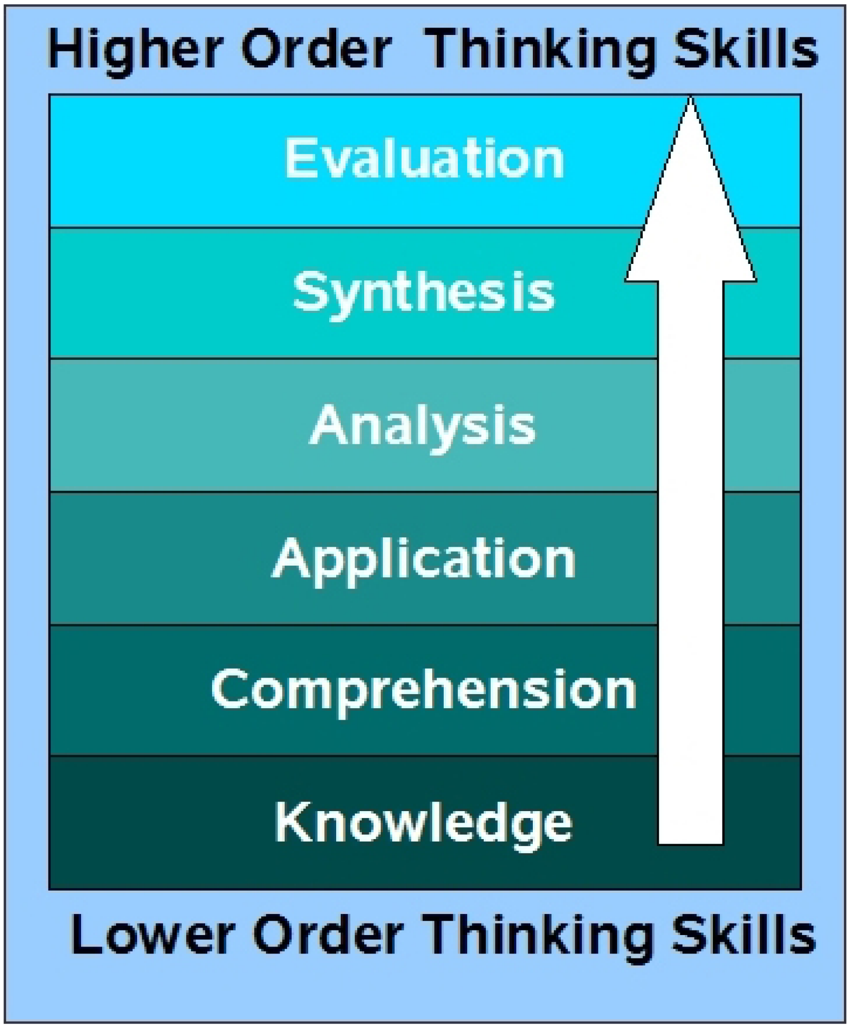

Figure 3.21: Cognitive levels (Bloom, 1956)

Receiving: Attention to particular phenomena or stimuli (activities, textbook, music, etc.). Attention ranges from simple awareness to selective attention	Ask, attend, choose, reply, receive, recognize
Responding: Active participation that involves attention (receiving) and reaction. Acquiescence in responding, willing attitude, and a display of satisfaction or dissatisfaction. Interest and emotion is exhibited	Behave, comply, cooperate, examine, obey, respond, observe, appreciate
Valuing: Worth or value attached to objects, people, or processes. Ranges from acceptance of value to complex levels of emotional commitment and responsibility toward values. Valuing is based on the internalization of a set of specific values and the actualization of these values in overt behavior. Behavior and emotions are consistent with values	Accept, balance, believe, defend, devote, influence, prefer, express, seek, value
Organization: Convergence of different values, resolution of value conflicts, and internally consistent value system. Emphasis on comparing, relating, and synthesis values. Individual is able to articulate how emotions and values are conceptualized and organized into value systems	Codify, commit, discriminate, favour, judge, order, organize, weigh, systematize, exhibit
Characterization: Individual has articulated a value system that has informed actions and emotions for periods sufficient to the development of a lifestyle. Behavior is consistent, value-driven, pervasive and predictable. Emotional patterns are mature and reflective. Individual is in touch with feelings	Internalize, verify, live according to

Table 3.10: Affective domain (Bloom, 1956)

(3) **Psychomotor:** It reflects the sensory, manipulative, and motor skills which is explained in Table 3.11 (Hauenstein, 1998; Petrina, 2006)

According to Hauenstein, the main concern of teachers are to take care of all the three domains, namely, cognitive, affective, and Psychomotor, in a balanced manner, as illustrated in Figure 3.22 (Hauenstein, 1998; Petrina, 2006).

As illustrated earlier in Chapter 2, students' deep learning occurrence needs not only the learning approach which is related to teaching context, but also the learning style which is related to students' preference for the learning approach (J. B. Biggs, 2011). According to the Bloom's Taxonomy, successful science and engineering education cannot be defined uniquely in terms of the number

Observing: The act of receiving ad recognizing a particular stimuli or phenomena (watching a demonstration, listening). Generally passive activity but with the senses responsive to stimuli. Involves the sensory reception of stimuli. Awareness of objects and relationships. Infers recognition and awareness. Tends to build sensory awareness	Distinguish, hear, see, smell, taste, touch
Imitating: The act of interpreting, translating and responding by repeating or stimulating an act in accordance with stimuli or phenomena (repeating word pronunciation, assuming a physical position, using a tool as shown). Dependent on the situation in which it was first encountered. Individual can display the sensory and motor actions necessary to repeat and act. Guided response through imitation and trial and error performance. Infers comprehension and responsiveness or basic interest. Tends to build skill conformity	React, focus, adjust, imitate, copy, position, prepare, approach
Manipulating: The act of valuing and applying knowledge to perform an action in an situation analogous or similar to that which it was originally imitated. Application of knowledge to similar situations (solving a new problem, trying out a new solution)	Simulate, duplicate, copy, determine, repeat, reproduce, emulate, model, match, approximate, adapt, practice, manipulate
Performing: The act of analyzing, synthesizing and organizing actions to act rationally and functionally. Meeting situations with confidence and performing in a variety of situations dissimilar to those of manipulation. Intellect, emotions and skills are developed to the point of ownership. Analyzing actions into parts to make new relationships consistent with values. Automatic and habitual phase of motor skills; applies sensory and motor skills as a matter of habit and intent. Infers analysis, synthesis and the organization of values	Assemble, calibrate, mold, set-up, maintain, operate, alter, retrofit, re-set, standardize, convert, order, correct
Perfecting: The act of evaluating and behaving with a high degree of sensory and motor skills, sensitivity, expertise and artistry. Highly independent activity seeking to creatively apply knowledge and skills. Understanding and control of knowledge, emotions and skills to achieve sophisticated levels of being. Internalization of knowledge is reflected in character and lifestyles. Judgments and decisions are consistent with values and knowledge. Infers evaluation and characterization. Tends to exhibit high level capabilities	Coordinate, integrate, regulate, design, devise, develop, originate, invent, formulate, automate

Table 3.11: Psychomotor skills (Bloom, 1956)

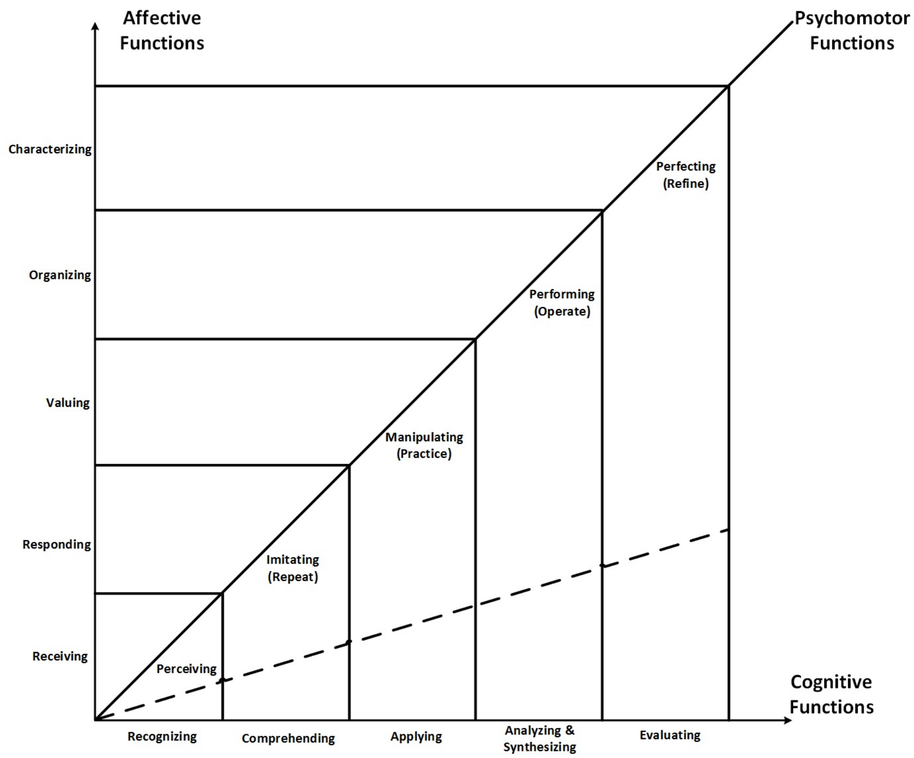

Figure 3.22: Domain vectors (Hauenstein, 1998)

of concepts and practices students learn. It should also include students' attitudes, beliefs, and expectations about learning that influences their behavior and performance (Bloom, 1956; Council, 2012). As a result, the work content of the flying house design session is associated with two domains of learning as follows:

- **Cognitive:** This domain of learning composed of students' knowledge and skills.
- **Affective:** This domain of learning refers to the feeling and attitude of students which can affect their learning process.

These principal learning components (i.e. knowledge, skills, and affect) are defined as

- **Knowledge:** Generally, it can be defined as familiarity, awareness, or comprehending of something (i.e., facts, information, descriptions, or skills) (Stevenson, 2010). Moreover, knowledge is a gathered database which can be used in proper time in order to be both the process and product of creative acts (Petrina, 2006). In other words, knowledge is the fact that people know the concepts they have acquired (Rugarcia, 2000). As discussed in (Nguyen & Zeng, 2012), knowledge is affected by two main factors such as its structure and the availability of cognitive resources. First, *the structure of knowledge depends on how the knowledge is structured and organized for efficient storage and retrieval*. One of the significant differences between experts and novices is the retrieval process of structured knowledge in problem solving. Second, *the availability of cognitive resources: according to information processing theory, past knowledge is believed to be retrieved from long term memory and to be held in working memory for use. Any factor that affects the availability of working memory, therefore, will affect knowledge activation*.

- **Skills:** It is known as reasoning which is used to examine or produce knowledge (Petrina, 2006). The abilities that people use in managing and applying their knowledge, such as computation, experimentation, analysis, synthesis/design, evaluation, communication, leadership, and teamwork (Rugarcia, 2000). Skills also can be identified as thinking manner, thinking mode which is referred to the ability of knowledge application to solve real problems. Skills are the tools used to manipulate the knowledge in order to meet a goal dictated or strongly influenced by the attitudes.

- **Affect:** Affect echoes the feeling, emotions, attitude, motive, and stress. Affect can determine the efficiency level of knowledge and skills which have been utilized for solving problems (Nguyen & Zeng, 2017; Tan, 2017). Hence, it is the feelings which are dictated to the goals toward their skills and knowledge that can be directedpersonal values, concerns, preferences and biases (Rugarcia, 2000).

As it is seen from Figure 2.2, the third part of this process is the assessment. The next Chapter introduces two different assessment methods based on the criteria which has to be measured in order to track the student learning.

3.2 Summary

In this Chapter, an Environment Based Design (EBD) approach has been used to develop the assessment criteria to understand that which factors should be considered in order to examine students' learning outcomes. As knowledge, skills, and affect have been chosen as criteria, Bloom's Taxonomy has been presented to make those criteria more clear.

Definition of each criteria in terms of design session is presented as follows:

Knowledge: Knowledge level in design fields such as design science, design process, and EBD.
Skills: Students' expertness in solving design problem for instance creative design and design thinking.
Affect: It is referred to the students' learning preference in a design session.

Chapter 4

Assessment Methods

This work has further investigated two methods beyond the traditional ones, especially covering the domains of conceptual understanding and affection assessment. The methods are: *Study Process Questionnaire (SPQ), Logos Comparison Task (LCT)*. These methods are expected to theoretically address the questions of what and how to measure from students' perspective. In measuring the effectiveness of student learning, the most significant problem relates to metrics of students' abilities (skills), learning level (knowledge), and motivation (affect) (Eftekhar, Strong, & Hawaleshka, 1996).

4.1 Case Study: Flying House Design

An Environment Based Design (EBD) session has been introduced by Dr. Zeng at Concordia University in summer 2017. The purpose of this session is to use EBD design methodology to solve a design problem and to monitor the influence of EBD on the creative design thinking. In this session, three cohorts of student from various discipline (Building and Architecture engineering, aerospace and Mechanics engineering, and Computer and Electrical engineering) were formed and was given an open-ended design problem to solve. In this context, students need to learn concepts using trial-and-error, searching various resources and testing their hypotheses. In addition, it is also expected that students employ critical thinking skills, problem solving skills, and decision making

(Vos, 2011).

4.1.1 Design task and Deliverable

The given design problem is ”*Design a house that can easily fly from one location to another location.*” The design deliverable is delivering three design concept alternatives in forms of design log and sketch by using different principles.

4.1.2 Task Assignment

The design problem has been divided into three different parts after analysis. Each part has been assigned to a certain student cohort based on their background and field of study. Finally, they will be merged into a larger group to integrate their designs later as follows:

(1) **House:** Design a house that can accommodate peoples daily activities.

(2) **Safety and control:** Design the part that helps the house interacts with the environment.

(3) **Flying:** Design the part that makes the house fly from one location to another location.

4.1.3 Task Description

The student cohorts were asked to deliver three different sketches for their assigned tasked. Afterwards, an hour EBD session has been taught to the students. Hereupon, the students cohorts tried to solve their assigned design problem under EBD and then they tried to integrate their solutions and their sketches until the final solution got evolved.

4.2 Measuring the Student Learning by Using Study Process Questionnaire (SPQ)

The Study Process Questionnaire (SPQ) was developed in the late 1970s from a 10 scale Study Behavior Questionnaire (SBQ) (J. Biggs, 2001). SPQ has been revised a couple of times. The ultimate version consists of two main approaches: surface (SA) and deep (DA). Each of the approaches contains two subscales. SA's subscales consist of surface motive (SM) and surface strategy (SS). On the contrary, DA's subscales consist of deep strategy (DS) and deep motive (DM). Each approach has 10 items (corresponding questions) and each subscale has 5 items. Scales and subscales of the questionnaire and their intentions are given in Table 4.1.

	Surface	Deep
Motive	Fear of failure	Intrinsic interest
Strategy	Narrow target, rote learn	Maximize meaning

Table 4.1: The original study process questionnaire dimensions, motives and strategies (J. Biggs, 2001)

Students' learning outcomes are a reflection of an educational system. The educational system can be represented based on the Presage-Process-Product (3P) model in Figure 4.1. The educational system is dynamic in which presage (i.e., student factors and teaching context), process (i.e., learning-focused activities), and product (i.e., learning outcomes) reciprocally interact as depicted in Figure 4.1. Presage shows the elements which can impact learning such as ability, prior knowledge, assessment, and students' preferred approaches to learn. The interactions of these elements determine students' current preferences of learning approaches and outcomes. Process level reflects the way that individuals treat specific tasks. Product level reveals the differences between different teaching methods. The Study Process Questionnaire (SPQ) intends to measure students' approaches to learning in the context of the 3P model (J. Biggs, 2001).

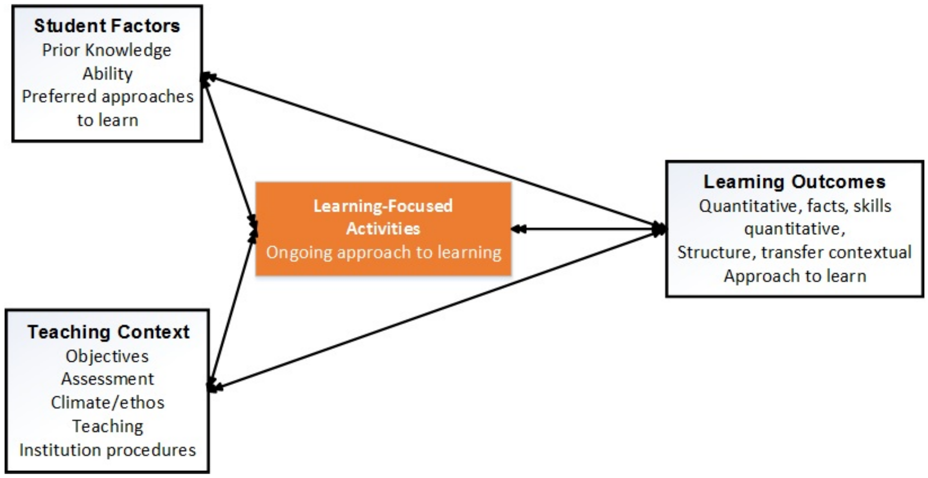

Figure 4.1: The 3P model of teaching and learning (J. Biggs, 2001)

To evaluate the approaches, students need to respond to the questionnaire (i.e., 20 questions) on a 5-point Likert scale from 'always true of me' to 'only rarely true of me'. The questions are predefined beforehand to the approaches and subscales. As samples, four questions are shown in Table 4.2. The complete version of questionnaire is provided in Appendix A.

Considering the entire questionnaire and the predefined assignments(J. Biggs, 2001), deep and surface approaches can be scored as summarized in Table 4.3. Further information about the questionnaire, student's rating, and relationships between the questions & surface/deep learning approaches can be found in (J. Biggs, 2001)s appendix.

4.2.1 SPQ Validation

The new version of SPQ has been tested with a sample of 495 students with diverse backgrounds in Hong Kong University to certify the reliability of each scale and subscale of the questionnaire. (Hu & Bentler, 1999) proposed to use standardized root mean squared residual (SRMR) and comparative fit index (CFI). CFI above 0.95 and SRMR below 0.8 can be interpreted as a goodness of fit between observed data and hypothesized one. Also, (Schmitt, 1996) proposed the Cronbach alpha values to confirm each sub-scale reliability. The Cronbach alpha values show 0.73 for DA and 0.64 for SA, which can be regarded as passable amounts. Results have been depicted in Table 4.4.

Questions
1. I find that at times studying gives me a feeling of deep personal satisfaction (example of DA & DM)
2. I find that I have to do enough work on a topic so that I can form my own conclusions before I am satisfied (example of DA & DS)
3. My aim is to pass the course while doing as little work as possible (example of SA & SM)
4. I only study seriously whats given out in class or in the course outlines (example of SA & SS)

Table 4.2: A sample questions of SPQ (J. Biggs, 2001)

Approach	Scoring
Deep approach	ΣAll Deep Motive scores + all Deep Strategy scores
Surface Approach	ΣAll Surface Motive scores + all Surface Strategy scores

Table 4.3: Deep and surface approaches scoring (J. Biggs, 2001)

Sub-Scales	CFI	SRMR	Alpha
Deep Motive (DM)	0.997	0.01	0.62
Deep Strategy (DS)	0.998	0.02	0.63
Surface Motive (SM)	0.988	0.02	0.72
Surface Strategy (SS)	0.998	0.02	0.57

Table 4.4: Reliability check for the four sub-scales (J. Biggs, 2001)

4.2.2 SPQ Usage in the Flying House Design Session

As discussed earlier, three student learning criteria have to be measured in order to extract student learning approach. Based on the Section 4.2, this questionnaire aids instructor to assess students' learning style (student preference). The students involved in this session are asked to answer the questionnaire before and after the EBD instruction. By comparing those answered questionnaire the instructor will be able to extract students' learning preference in terms of deep approach to learn and surface approach to learn. Furthermore, it helps the instructor to discern whether this EBD session motivates the students to change their learning style. The advantages of this questionnaire are being totally focused on the thesis assumption based on the considered learning approaches which are surface and deep. Moreover, due to the lower number of questions, students are more eager to answer those questions in such a way that is more truthful.

4.3 Measuring the Student Learning by Using Logos Comparison Task (LCT)

This question has been designed by Dr. Yong Zeng at Concordia University as one of the final exam questions for course Product Design and Methodology (INSE6411) which is taught by himself. Through this course, students learn design methods for being innovative and creative in design by leaning Environment Based Design (EBD) (Zeng, 2004a). It helps the students to expand their knowledge about design science and design process as well as heightening their design thinking and design skills. Therefore, it is expected to be comfortable for them to face new design problems in terms of environment analysis and conflict identification for offering creative design solutions ("Product Design and Methodology", 2018).

4.3.1 Task Description

Logo design is all around us. To the general public, logos serve as an instant reminder of an organization or a product; to the client they're the point of recognition on which their branding hangs. Please evaluate and compare the old Concordia University logo which is shown in Figure 4.2 and the new Concordia University logo which is depicted in Figure 4.3. Please explain which one is better and why it is better. Please use EBD to answer this task if you know EBD.

4.3.2 Comparison Task Usage

To answer this question, students needs to be familiar with design process and design knoeledge. Also, they need to know the EBD steps and the interaction between those steps as the steps are simultaneously and recursively interdependent (Zeng, 2004a, 2004b). Moreover, being creative is a key to success as it is interpreted as design skill which is called design thinking. Accordingly, this task aids to elicit and monitor student knowledge and skills in terms of design process, design methods, and design thinking.

Figure 4.2: Old Concordia University logo

Figure 4.3: New Concordia University logo

4.4 Discussion & Summary

In this Chapter, a flying house design session has been introduced as case study. In order to evaluate the effectiveness of student learning, SPQ and logos comparison task are used subjectively in the context of this session.

The methods to measure the effectiveness of student learning are assumed to be related to knowledge, skills, and affect as given in Table 4.5. The comparison task can reveal students' preconceptions and help both the instructors and students to monitor students' progress from a naive to a more expert-like understanding (MacIsaac, 2015). Perceived student's learning approaches and preferences elicited in SPQ can help monitoring the students' affective domain. Table 4.5 discusses the relationships between methods in terms of measuring the effectiveness of student learning in the flying house design session.

Method	Knowledge	Skills	Affect
SPQ	✗	✗	✓
Logos Comparison Task	✓	✓	✗
✓	Support		
✗	Not Support		

Table 4.5: Assessment methods related to knowledge, skill, and affect

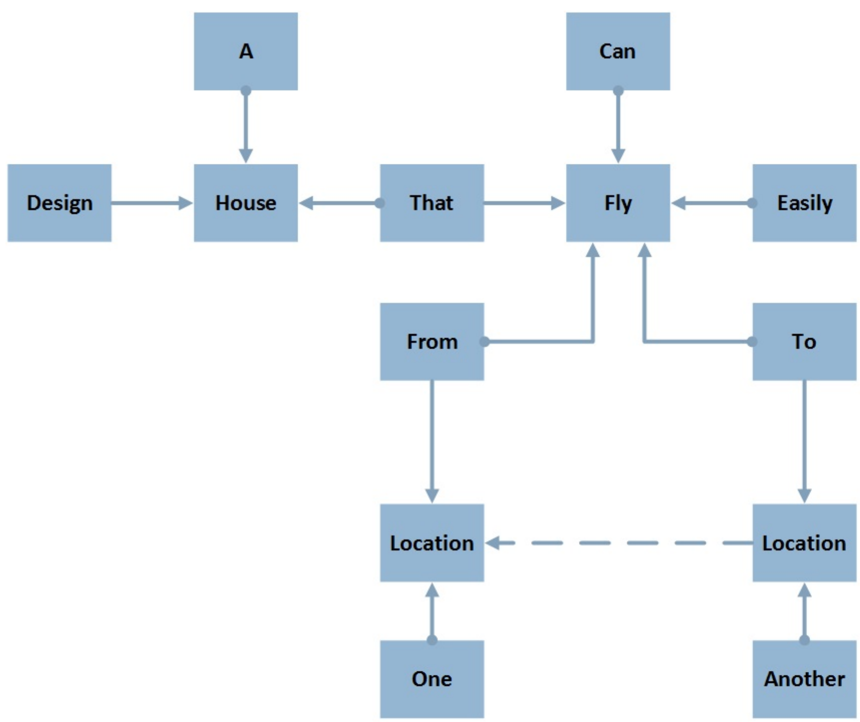

Figure 4.4: Design problem ROM diagram

Chapter 5

Results and Discussion

The instructional design emphasizes the importance of assessment in conjunction with content (or curriculum) and instruction (or pedagogy) (MacIsaac, 2015). In this context, the instruction is a flying house design session.

The Logos Comparison Task (LCT) are suitable in terms of assessing students' knowledge and skills. This task needs to be further explored to understand its usefulness, when/how often to measure (e.g., diagnostic, formative, or summative assessment) (Handbook, 2008; MacIsaac, 2015), how to capture students' conceptual representations, what should be the ideal conceptual representation, and how to reduce/close the gap between the ideal conceptual representations and the captured ones. In addition, other considerations are needed to acquire/differentiate individual learning and group learning.

Even though the cognitive aspects of learning can be potentially assessed by LCT, the theory of learning suggests that assessment of the affective domain (e.g., student's attitude, beliefs, and expectations) is still inevitable which may influence the motivation and performance of students (Crawley, 2010). Results of affection assessment can help the program designer to elevate the students' motivation and reduce the aversion (Crawley, 2010). The SPQ questionnaire has been used to tackle this issue by assessing the students' learning approach in terms of student deep learning approach and student surface learning approach.

5.1 Data Collection

To collect data, 20 students were categorized into two different groups. Each group contains 10 students all post secondary educated. The first group were familiar with EBD as a design methodology. The second group were unfamiliar with EBD and any other design methodology.

The students of each group were asked to fill up the SPQ questionnaire and execute the Logos Comparison Task (LCT). The students had no time limit to do the comparison task and filling up the questionnaire. Table 5.1 and Table 5.2 show the gathered data from EBD students group and non-EBD students group respectively.

5.2 Data Analysis

It is hypothesized that the students with EBD knowledge are stronger in solving the design task (LCT) and they can achieve relatively better grades. Moreover, it is hypothesized that the students with deep learning approach are more likely to achieve higher grades. To test those hypothesizes, a 2^k **factorial experiment** ("experiment design and analysis reference", unkown) in which k is the number of factors has been used to investigate and determine the influence of EBD and SPQ on the students' grades in solving logos comparison task.

Factorial experiment is such an experiment in which the all compound of factors will be examined in each iteration of experiment. It is investigating the effect of each factor and the interaction between factors on the output of the experiment.

Suppose that there are n observation $y_{i,j}$, $i = 1, ..., 2^k; j = 1, ..., n$ that are made in each of each of the 2^k runs. Hence the sample mean of data in each run calculated as:

$$\bar{y_i} = (\Sigma_j^n y_{ij})/n \tag{3}$$

EBD		
Subjects	**Methods**	
	SPQ (Deep/Surface)	**LCT**
1	**2.04**	**13**
2	**2.36**	**3**
3	**1.8**	**13**
4	**1.77**	**11**
5	**1.51**	**3**
6	**.75**	**11**
7	**.64**	**9**
8	**1.06**	**18**
9	**1.3**	**20**
10	**1.17**	**9**

Table 5.1: EBD students group data

Non-EBD		
Subjects	**Methods**	
	SPQ (Deep/Surface)	**LCT**
1	**1.69**	**3**
2	**1.85**	**3**
3	**1.34**	**3**
4	**2.29**	**3**
5	**1.78**	**3**
6	**1.03**	**3**
7	**1.25**	**3**
8	**1.12**	**3**
9	**0.95**	**3**
10	**1.27**	**3**

Table 5.2: Non-EBD students group data

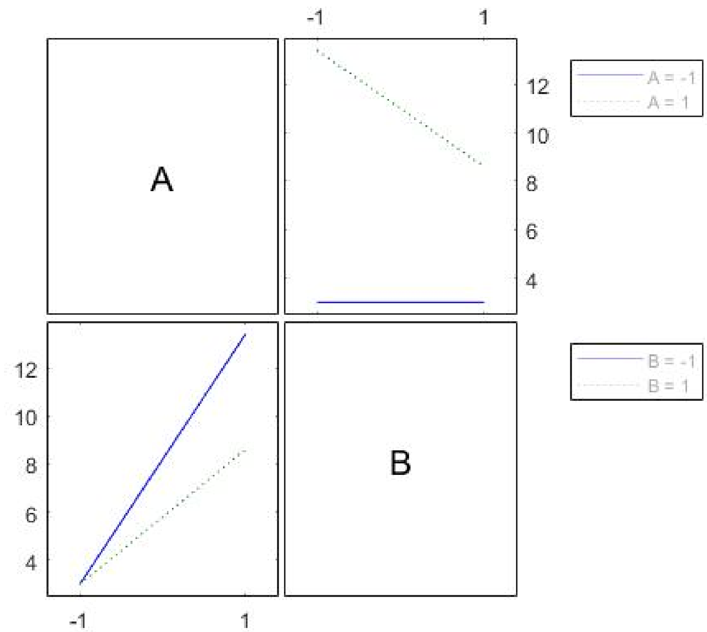

Figure 5.1: Interaction plot between EBD and SLA

The grand mean is given by:

$$\bar{\bar{y}} = \frac{1}{2^k}\sum_{i=1}^{2^k}\bar{y}_i = \frac{1}{2^k n}\sum_{i=1}^{2^k}\sum_{j=1}^{n} y_{ij} \tag{4}$$

This is a 2^k factorial experiment with $k = 2$ and $n = 5$. Figure 5.1 shows the interaction between EBD knowledge and skills and the Students' Learning Approach (SLA) on LCT grades.

According to the interaction plot, there is no interaction between EBD knowledge and skills and students' learning approach.

The MATLAB analysis of variance results is shown in Figure 5.2. From the ANOVA Table, the hypothesizes will be tested based of the F-test statistics for factor EBD and SLA and the interaction between two factors.

Analysis of Variance

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
EBD	320	1	320	23.66	0.0002
SLA	28.8	1	28.8	2.13	0.1639
EBD*SLA	28.8	1	28.8	2.13	0.1639
Error	216.4	16	13.525		
Total	594	19			

Constrained (Type III) sums of squares.

Figure 5.2: ANOVA table for factorial experiment

At significance level $\alpha = 0.05$, an effect is considered significant at level α if: $f_{ratio} > f_{\alpha,1,2^k(n-1)}$.

Afterwards, the F-test is conducted to see the influence of EBD and SLA on LCT grades.

(1) **F-test for factor EBD:**

- **Step 1:** The hypothesis of no main effect of factor EBD on LCT grades is tested:
- **Step 2:** The value of the F-test statistics for factor EBD is $f_{ratio} = 23.66$. Hence:

  $f_{0.05,1,16} = 4.4940 < f_{ratio} = 23.66$
- **Step 3:** Since $f_{ratio} < f_{\alpha,1,2^k(n-1)}$, we reject the null hypothesis H_0. Thus, we have sufficient evidence to indicate a significant effect of EBD on LCT grades.

(2) **F-test for factor SLA:**

- **Step 1:** The hypothesis of no main effect of factor SLA on LCT grades is tested:
- **Step 2:** The value of the F-test statistics for factor SLA is $f_{ratio} = 2.13$. Hence:

  $f_{0.05,1,16} = 4.4940 > f_{ratio} = 2.13$
- **Step 3:** Since $f_{ratio} < f_{\alpha,1,2^k(n-1)}$, we do not reject the null hypothesis H_0. Thus, we have insufficient evidence to indicate a significant effect of SLA on LCT grades.

(3) **F-test for interaction between EBD and SLA:**

- **Step 1:** The hypothesis of no main interaction between EBD and SLA:
- **Step 2:** The value of the F-test statistics for interaction between EBD and SLA is $f_{ratio} = 2.13$. Hence:

  $f_{0.05,1,16} = 4.4940 > f_{ratio} = 2.13$
- **Step 3:** Since $f_{ratio} < f_{\alpha,1,2^k(n-1)}$, we do not reject the null hypothesis H_0. Thus, we

have insufficient evidence to indicate a significant interaction between EBD and SLA.

Likewise, to study the relation between the students' deep learning approach and the LCT grades, a linear regression analysis is conducted for a group of 10 students who have EBD knowledge and skills. Figure 5.3 depicts that the data is highly scattered and seemingly there is no linear relation between the data and the regression line.

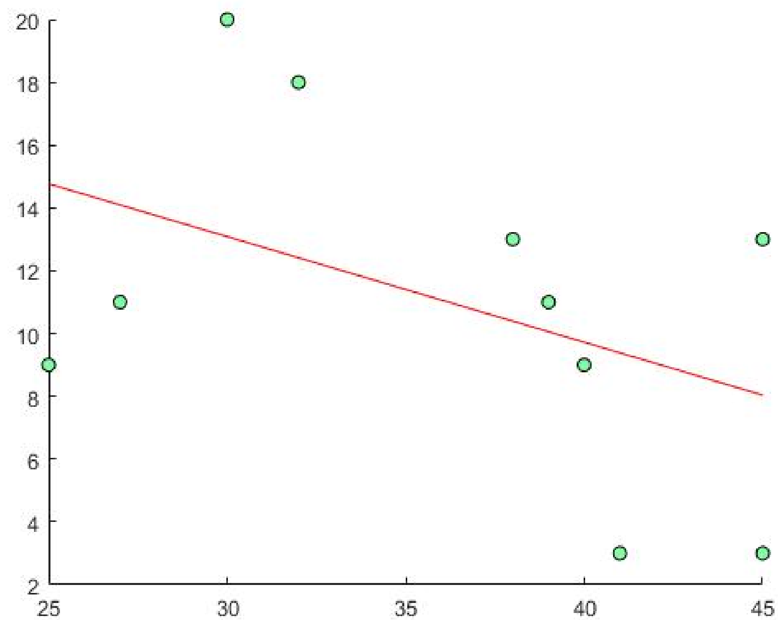

Figure 5.3: Scatter plot and regression line of the SLA and EBD data

To judge the relationship between SLA and LCT grades, the analysis of variance Table is presented to test the significance of linear regression for the LCT grades. The first step to create ANOVA Table is defining regression equations as follows ("experiment design and analysis reference", unkown).

It is assumed that each observed value y_i of the response variable Υ_i can describe as follows:

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i, \quad i = 1, ..., n \tag{5}$$

Where

- yi is the variable that should be predicted or explained
- x_i is the independent variable used to predict or explain yi

• β_0 and β_1 are unknown parameters, intercept and slope of the line, respectively

• $\varepsilon_i \sim N(0, \sigma^2)$ is a random error with unknown variance

To fit the linear regression model 5 by using least square method to find the unknown variables β_0, β_1 by minimizing the sum of squared deviations:

$$L = \sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} (y_i - (\beta_0 + \beta_1 x_i))^2 \tag{6}$$

By simplifying the sum of square equation, $\hat{\beta_0}, \hat{\beta_1}$ which are an estimate for β_0, β_1 respectively.

$$\begin{cases} \hat{\beta_0} = \bar{y} - \hat{\beta_1}\bar{x} \\ \hat{\beta_1} = \frac{\Sigma_{i=1}^{n} x_i y_i - n\bar{x}\bar{y}}{\Sigma_{i=1}^{n} x_i^2 - n\bar{x}^2} = \frac{S_{xy}}{S_{xx}} \end{cases} \tag{7}$$

S_{xx} and S_{xy} can be written as:

$$S_{xx} = \sum_{i=1}^{n} x_i(x_i - \bar{x}) \quad S_{xy} = \sum_{i=1}^{n} y_i(x_i - \bar{x}) \tag{8}$$

However to calculate ANOVA Table, an estimate of SS_T (*total sum of square*), SS_R (*regression sum of square*), and SS_E (*error sum of square*) is needed. The following equation represent those terms in mathematic forms.

$$SS_T = \Sigma_{i=1}^{n} (y_i - \bar{y})^2 \tag{9}$$

$$SS_R = \frac{S_{xy}^2}{S_{xx}} \tag{10}$$

$$SS_E = SS_T - SS_R \tag{11}$$

Similarly, the MS_R (*mean square regression*) and MS_E (*mean square error*) is calculated by dividing them on their degree of freedom which are 1 and (n - 2) respectively as follows:

$$MS_R = SSR/1 \tag{12}$$

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F0
Regression	SS_R	1	MS_R	MS_R/MS_E
Error	SS_E	$n-2$	MS_E	
Total	SS_T	$n-1$		

Table 5.3: Analysis of Variance for testing significance of regression

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F0
Regression	53.1601	1	53.1601	1.9257
Error	220.8399	8	57.6050	
Total	274	9		

Table 5.4: Analysis of Variance for LCT data

$$MS_E = SS_E/(n-2) \tag{13}$$

Now it it is possible to calculate the F-test as follows:

$$F_{ratio} = \frac{SS_R/1}{SS_E/(n-2)} \tag{14}$$

Table 5.3 shows the components of an ANOVA Table. By calculating those components based on the LCT data, the related ANOVA Table is created as depicted in Table 5.4.

The significance of regression using ANOVA with $\alpha = 0.05$ is tested. The rejection region is $f_{ratio} > f_{\alpha,1,n-2}$.

• **Step 1:** Test the hypothesizes:

$$\begin{aligned} \boldsymbol{H_0} &: \text{ There is no significant linear relationship} \\ \boldsymbol{H_1} &: \text{ There is a significant linear relationship} \end{aligned}$$

• **Step 2:** The value of the test statistic is $\boldsymbol{f_{ratio} = 1.9257}$. Hence,

$\boldsymbol{f_{0.05,1,8} = 5.3177 > f_{ratio} = 1.9257}$

• **Step 3:** Since $\boldsymbol{f_{ratio} < f_{\alpha,1,(n-2)}}$, we do not reject the null hypothesis $\boldsymbol{H_0}$. Thus, we have insufficient evidence to indicate a significant linear relationship between student deep learning approach and higher LCT grades.

5.3 Summary

Two different hypothesis have been tested based on the factorial experiment and regression analysis. By conducting Analysis of Variance (ANOVA) based on the factorial experiment the results reveal that:

• EBD knowledge and skills has a significant impact on students' grades for logo comparison task.

• There is not enough evidence to indicate a significant effect of students' learning approack (SLA) on students 'grades related to Logos Comparison Task (LCT).

• There is not enough evidence to indicate a significant interaction between EBD and SLA.

From the regression analysis, as Figure 5.3 shown, there is no significant linear relationship between students' grades on LCT and students' deep learning approach. In order to certify that, F-test statistics has been councuted based on ANOVA Table 5.4. Since $\boldsymbol{f_{ratio} < f_{\alpha,1,(n-2)}}$ there is no linear relationship between LCT grades and students' deep learning approach.

Chapter 6

Conclusion & Future Work

Recently, industry and academia requirements for new graduates have changed in terms of students' readiness level to conduct interdisciplinary research. In traditional lecture-based and assessment systems, students are encouraged to use surface learning approach to solve textbook problems without exposing and equipping students to/with the abilities to solve the real engineering problems. In order to lead students to deep learning and seek fundamental concepts and structures, Problem-Based Learning (PBL) in engineering have been proposed all over the world. There are yet challenges in assessing and understanding the effectiveness of learning in the PBL.

The Environment Based Design (EBD) methodology has been introduced as the theoretical foundation. Moreover design logic and design mathematical foundation have been presented. The assessment criteria have been identified by using Environment Based Design (EBD). It showed that three learning components (knowledge, skills, and affect) are the assessment criteria to measure the students' learning outcomes in terms of the students' learning approach. Furthermore, presence of a deep teaching context has been necessitated in which the students improve their knowledge and skills. This is also the case and intention of the flying house design session as a case study.

This work have explored the potential of two assessment methods to measure the effectiveness of student learning during the flying house design session: SPQ and LCT. To compare methods against each other, in terms of feasibility and objective function, SPQ helps to track and extract students' affective domain. Furthermore, LCT is able to evaluate students' design knowledge and skills.

This work investigated different hypothesis by applying those methods on two groups of student: The first group with EBD knowledge and second group without EBD knowledge. Data analysis results illustrated that:

- EBD knowledge and skills has a significant impact on students' grades for logo comparison task.
- There is not enough evidence to indicate a significant effect of students' learning approack (SLA) on students 'grades related to Logos Comparison Task (LCT).
- There is not enough evidence to indicate a significant interaction between EBD and SLA.
- There no significant linear relationship between students' grades on LCT and students' deep learning approach.

Besides the suggested explorations, additional future work may include the three following subjects.

- Individual and group assessments should be differentiated, measured and understood.
- The fitness/limitations for each of the explored methods in Chapter 4 should be evaluated in detail for each task/work content in the flying house design session. This exploration can highlight the need to include, combine or remove some of the methods.
- Implementation paths to use the assessment should be explored to enlighten/improve the flying house design session instructions for future student cohorts.
- The self-assessment accuracy has to be investigated and improved in order to narrow down the gap between students' real status and their perception about themselves.

Appendix A

My Appendix

Revised Study Process Questionnaire (R-SPQ-2F)

This questionnaire has a number of questions about your attitudes towards your studies and your usual way of studying.

There is no right way of studying. It depends on what suits your own style and the course you are studying. It is accordingly important that you answer each question as honestly as you can. If you think your answer to a question would depend on the subject being studied, give the answer that would apply to the subject(s) most important to you.

Please fill in the appropriate circle alongside the question number on the General Purpose Survey/Answer Sheet. The letters alongside each number stand for the following response.

A — this item is never or only rarely true of me

B — this item is sometimes true of me

C — this item is true of me about half the time

D — this item is frequently true of me

E — this item is always or almost always true of me

Please choose the one most appropriate response to each question. Fill the oval on the Answer Sheet that best fits your immediate reaction. Do not spend a long time on each item: your first reaction is probably the best one. Please answer each item.

Do not worry about projecting a good image. Your answers are CONFIDENTIAL. Thank you for your cooperation.

1. I find that at times studying gives me a feeling of deep personal satisfaction.
2. I find that I have to do enough work on a topic so that I can form my own conclusions before I am satisfied.
3. My aim is to pass the course while doing as little work as possible.
4. I only study seriously whats given out in class or in the course outlines.
5. I feel that virtually any topic can be highly interesting once I get into it.
6. I find most new topics interesting and often spend extra time trying to obtain more information about them.
7. I do not find my course very interesting so I keep my work to the minimum.
8. I learn some things by rote, going over and over them until I know them by heart even if I do not understand them.
9. I find that studying academic topics can at times be as exciting as a good novel or movie.
10. I test myself on important topics until I understand them completely.
11. I find I can get by in most assessments by memorizing key sections rather than trying to understand them.
12. I generally restrict my study to what is specifically set as I think it is unnecessary to do anything extra.
13. I work hard at my studies because I find the material interesting.
14. I spend a lot of my free time finding out more about interesting topics which have been discussed in different classes.
15. I find it is not helpful to study topics in depth. It confuses and wastes time, when all you need is a passing acquaintance with topics.
16. I believe that lecturers shouldn't expect students to spend significant amounts of time studying material everyone knows wont be examined.
17. I come to most classes with questions in mind that I want answering.

18. I make a point of looking at most of the suggested readings that go with the lectures.

19. I see no point in learning material which is not likely to be in the examination.

20. I find the best way to pass examinations is to try to remember answers to likely questions.

Scoring is in the following cyclical order:

1. Deep Motive, 2. Deep Strategy, 3. Surface Motive, 4. Surface Strategy.

Deep Approach Score: Σ All Deep Motive scores + all Deep Strategy scores

Surface Approach Score: Σ All Surface Motive scores + all Surface Strategy scores

Approach	**Scoring**
Deep approach	ΣAll Deep Motive scores + all Deep Strategy scores
Surface Approach	ΣAll Surface Motive scores + all Surface Strategy scores

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