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Problem-Based Learning (PBL) in the College Chemistry Laboratory: Students' Perceptions of PBI and Its Relationship with Attitude and Self-Efficacy Beliefs

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PROBLEM-BASED LEARNING (PBL) IN THE COLLEGE CHEMISTRY LABORATORY: STUDENTS' PERCEPTIONS OF PBL AND ITS RELATIONSHIP WITH ATTITUDE AND SELF-EFFICACY BELIEFS

by

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A convergent mixed methods research study was used to investigate whether or not students who participated in the problem based learning (PBL) environment improved their self-efficacy beliefs (SEBs) in and attitudes toward chemistry. The study also investigated the students' views of the PBL environment. The Chemistry Attitude and Experience Questionnaire (CAEQ) was used as a pre- and post-test to determine changes in students' attitudes and SEBs. The PBL Environment Inventory (PBLEI) was used to investigate students' views of the PBL environment. Confirmatory factor analysis was used to re-validate both instruments with the study group: students in general chemistry laboratories at a Midwestern university in the USA. Interviews were used to augment the quantitative data. Paired sample t-tests were used to determine the difference in means between pre- and post-tests. Analysis of variance was used to determine the influence of confounding variables. Relationships amongst instrument variables and PBL, SEBs, attitudes, and PBLEI were investigated through multiple correlations and multiple linear regressions. A positive relationship was observed between PBL and students' SEBs using both qualitative and quantitative data. Quantitative data showed no influence of PBL on students' attitudes. Surprisingly, the qualitative data indicated improved students'

attitudes toward chemistry. Results from both qualitative and quantitative data also showed that students had a positive view of the PBL environment. Correlation and regression results indicate a positive relationship between variables of the PBLEI. Furthermore, a positive relationship was observed amongst attitudes, SEBs, and students' views of the PBL environment. Regression data showed that scores on SEBs and attitudes contributed significantly to the explanation of each other. SEBs scores also contributed significantly to PBLEI scores. However, no significant contribution was observed between attitudes and PBLEI.

Generally, our results indicate that PBL has a potential for improved students' outcomes in the affective domain including attitudes toward chemistry and self-efficacy beliefs. This study may add knowledge to research on the effects of PBL instruction and strengthen existing information in the PBL and affective domain. From the results of this study, chemistry laboratory instructors may be well informed whether or not to adopt PBL as a mode of instruction.

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CHAPTER 1

INTRODUCTION

Statement of the Problem

Russell (2004) claims that classroom relations have a direct impact on the learning environment. Griffith and Nguyen (2006) argue that feelings and emotions are indispensable components of classroom interactions and learning. That is, how individuals feel may determine the level of commitment to their classroom work. Although the major purpose of learning is to enable students to master specific skills, ignoring the affective domain can greatly reduce the efficiency at which these skills are mastered (Griffith & Nguyen, 2006). According to Adkins (2004), most educational institutions focus on teaching cognitive skills at the expense of affective ones. However, Adkins believes that developing cognitive skills without considering the affective domain is forgetting the whole purpose of education. There is enough evidence to suggest that affective factors correlate with performance in the cognitive domain (Bloom, 1979). For instance, affective factors such as attitude, self-efficacy beliefs, motivation, and anxiety have been shown to influence students' learning (Kan & Akbaş, 2006). There is a growing body of research examining the factors that improve students' affect (Jungert & Rosander, 2010; Keller, 1987; Moos & Azevedo, 2009). From these studies, classroom environment has been among the top contributors to improved affect (Meyers & Fouts, 1992; Nolen, 2003).

Problem-based learning (PBL) as a classroom environment has been generally shown to improve both the cognitive and affective domains (Chin & Chia, 2006; Yalcin, *et al.*, 2006). PBL is an instructional approach where students actively solve ill-structured problems with the guidance of an instructor (Barrows, 1988). Most studies in PBL focus on its connection with classroom performance, critical thinking, and the students' views about the instructional approach (Alessio, 2004; Tarhan & Acar, 2007). Surprisingly, very little attention has been paid to the influence of PBL on attitudes and self-efficacy beliefs in chemistry. Most of the studies in the affective domain have occurred at the middle and high school levels (Cheng, 2000; Turkmen, 2007). Furthermore, these studies occurred in science disciplines other than chemistry (Cheng, 2000; Turkmen, 2007). Even among the few studies conducted, the methodologies and results are not conclusive. Therefore, this was an attempt to investigate the effects of PBL laboratory units on students' self-efficacy beliefs in and attitudes towards chemistry.

Purpose of the Study

The purpose of this study was to investigate what changes in attitudes toward and self-efficacy beliefs in chemistry occur on students learning chemistry laboratory through PBL. The study also investigates the students' views of the PBL environment. This has been investigated using a mixed-methods embedded design. One survey instrument was used to determine the relationship between students' self-efficacy beliefs and attitudes, and another measured their views of the PBL environment. A follow up interview provided additional, richer data to the quantitative data. In all, this study addresses four research questions:

1. What changes in attitudes toward chemistry occur when students participate in a

PBL laboratory unit?

2. What changes in self-efficacy beliefs in chemistry occur when students participate in a PBL laboratory unit?
3. What are the students' views of the PBL environment?
4. What is the relationship between chemistry students' views of the PBL environment, their self-efficacy beliefs in, and their attitudes toward chemistry?

Definitions

In this section, I define important terms that have been used in this study. These include the three focus areas for this study: PBL, self-efficacy beliefs, and attitudes.

Problem-Based Learning (PBL)

According to Barrows (1988), PBL is a constructivist educational approach where curriculum and instruction are organized around carefully crafted ill-structured problems. In this approach, teachers act as cognitive coaches to develop students' critical thinking, problem solving, and collaborative skills (Ram, 1999). Usually, students are required to identify problems through discussions after which they formulate hypotheses and use several sources of information to develop procedures for investigating their hypotheses. Then they conduct activities to investigate the validity of their hypotheses. Most of the work is done by students, and the instructor's role is ensuring that the learning process is properly guided. There are several PBL models but the widely used ones are the McMaster and the hybrid models (Barrows 1998). In the McMaster model, PBL applies to the whole curriculum such that learning is through solving problems. This one is mostly used in medical fields. In contrast, other disciplines (e.g., sciences) usually use the hybrid model. In this model, PBL is just used for specific topics or courses. For this research project, PBL is defined as an instructional approach where students actively solve ill-structured problems with the guidance of an instructor.

Constructivism

Constructivism is a theory that posits that individuals construct knowledge through interaction with their environment (Piaget & Inhelder, 1958; Vygotsky, 1978). In this study, constructivism is defined as a process by which individuals construct meaning of phenomena by interacting with or experiencing the environment where the phenomena occur.

Constructivist Approach

Constructivist approaches are instructional strategies developed in response to the theory of constructivism. These instructional strategies encourage students to construct knowledge through interactions with their environment by getting actively involved in their learning process (Bodner, 1986). In this study, the constructivist approaches are defined as the instructional strategies that encourage students to construct meaning of phenomena by being actively involved in the learning process.

Attitude

Various authors have defined the term attitude in different ways. This indicates that there is not a single clear definition of this term. Koballa and Glyn (2007) reveal that authors usually use the term attitude interchangeably with other terms such as interests, beliefs, curiosity, and opinions. In their review of literature, Osborne, Simon, and Collins

(2003) found that studies related to attitude towards science had titles like ‘anxiety towards science’, ‘self-esteem towards science’, ‘motivation for science’, and other affective terms. According to Gagne (1979), attitudes have a significant role in influencing the individual’s choice. To him, attitude is a state of readiness that is acquired through experience and affects individual response to situations. In simple terms, attitude relates to emotional responses to specific phenomenon such as a teaching approach, a course, or a location (Simpson & Oliver, 1990). My operational definition of attitude is the one proposed by Simpson and Oliver (1990) because it is general and simple.

Self-Efficacy Beliefs

Bandura (1986, p. 391) defines self-efficacy beliefs (SEBs) as “people’s judgments of their capabilities to organize and execute courses of action required to attain designated types of performances”. This construct deals with people’s judgements about their capabilities and not on the skills that they posses. Self-efficacy theory was propagated by Bandura (1977) in his unifying theory of behavioral change. In this theory, he discussed cognitively-based sources of motivation to set and achieve specific goals. Bandura (1994) believes that individuals with higher perceived SEBs have a greater commitment to accomplish difficult tasks because they are confident in their capabilities. In contrast, those with low perceived SEBs beliefs are likely to stop performing tasks once they meet difficulties. Bandura’s (1986) definition has been used as the operational definition of self-efficacy in this review.

The Learning Environment

According to Lippman (2010), the learning environment has four components: the learner, other students, the teacher, and the physical environment. Research has shown that the learning environment plays a crucial role in determining the students' learning outcomes and attitudes towards science. In this study, the learning environment is defined as a condition under which instruction occurs.

Situated Learning Theory

Situated learning is a theory that proposes that the subject matter must be embedded in the students' ongoing experiences (Lave & Wenger, 1991). According to Lave and Wenger (1991), learning depends on the activity, context, and culture and is usually unintentional. Hence, situated learning places context as a vital factor for effective learning. In this study, situated learning is defined as an instructional process where learning takes place in the context of application.

Theoretical Framework

Two theoretical frameworks, constructivism and the Theory of Planned Behavior (TPB), have shaped this study. On the one hand, constructivism is key to describing the instructional approach (PBL). Constructivism is inherent in the PBL instructional approach, hence is the appropriate learning theory in this study. Since the instructional approach cannot be separated from the constructs (self-efficacy beliefs and attitudes) this study intends to investigate, it is necessary to understand the theory behind it, hence the need for TPB. This understanding will provide a clear picture of the changes that occur in both students' chemistry self-efficacy beliefs and attitudes. On the other hand, TPB encompasses self-efficacy beliefs and attitudes and understanding this theory and its assumptions will determine how the researcher interprets data from this study. These two theories have been discussed below.

Constructivism

The learning theory used in this study is constructivism because PBL exemplifies the aspects of constructivist teaching approaches. The constructivist theory of knowledge was popularized by Jean Piaget. According to Piaget, knowledge is a result of people's interaction with the world through experience and processes that help to integrate this knowledge into the brain (Piaget & Inhelder, 1958). This theory combines aspects from both empiricists and nativists by combining the influence of innate abilities and environmental factors.

Constructivists assert that people acquire knowledge by constructing meaning based on their experiences with the environment (Piaget & Inhelder, 1958; Richardson, 2003; Vygotsky, 1978). While Piaget's theory emphasized an individual, Vygotsky extended it to society. Due to the differences in emphasis between the two psychologists above, constructivism had two major divisions: "social constructivism" and "psychological constructivism" (Kemp, 2000). On the one hand, social constructivists argue that economic, social, and political environments are important for learning to take place (Vygotsky, 1978; Phillips, 1997). On the other hand, psychological constructivists believe that meaning and how it is created in an individual is paramount to developing formal knowledge within groups (Piaget & Inhelder, 1958; Richardson, 2003).

Piaget and Inhelder (1958) observed that children learn through organizing information into what Piaget referred to as schemes. In these schemes, information is categorized based on similarities in processing it. As the child gets new information, he/she puts it into the pre-existing schemes (assimilation). However, information that does not fit into the existing schemes is accommodated by transforming existing schemes or creating new ones (accommodation). The learner constructs meaning through the interaction between these schemes and the environment. This suggests that a variety of environments are likely to accelerate students' learning and development. Piaget's emphasis was on the student as an individual.

Conversely, Vygotsky (1978) claimed that learning and development was a result of students' interactions with the social structures of their environment. Vygotsky (1978) coined the term Zone of Proximal Development (ZPD), which was an observation that children learned particular tasks with guidance from the instructors or other students. Therefore, Vygotsky (1978) emphasized the social aspects of learning. In summary, students must be guided to discover knowledge. However, both Piaget and Vygotsky acknowledged that learners construct their knowledge through interaction with their environment (constructivism). Constructivism is a philosophical view of human understanding characterized by three primary propositions (Savery & Duffy, 2001). The three propositions are:

- Understanding develops through interactions with the environment.
- Cognitive conflict or puzzlement is the stimulus for learning and determines the organization and the nature of what is learned.

- Knowledge evolves through social negotiation and through the evaluation of the viability of individual understandings.

Bodner (1986, p. 873) summarizes the constructivist approach in education as an approach where " knowledge is constructed in the mind of the learner". Constructivist approaches are learning styles which are in line with the thinking behind constructivism. These approaches encourage students to be actively involved in their own learning by solving problems (e.g., PBL) or answering deep cognitive questions (inquiry).

Situated Learning and Constructivism

Constructivism was not developed in the field of education, rather it was developed in the field of psychology. However, educators found constructivism appealing and derived learning theories from it. One such theory is the situated learning theory developed by Jean Lave and Etienne Wenger (1991). Situated learning is derived from Vygosky's (1978) activity theory. In summary, activity theory states that the behaviors that we observe from individuals in their social environment are related to how their minds process information (Clancey, 1995; Vygosky, 1978). As a result, knowledge has a strong correlation to social factors and is effectively acquired in collaborative processes. Situated learning therefore extended Vygosky's ideas to education.

According to situated learning theory, students' tend to understand better when they are given opportunities to get actively involved in the instructional process (Lave & Wenger, 1991; Stein, 1998). Proponents of this theory recommend that the subject matter be embedded in the students' ongoing experiences (Lave & Wenger, 1991). Lave and Wenger (1991) reveal that "rather than asking what kinds of cognitive processes and conceptual structures are involved, [situated learning proponents] ask, what kinds of social engagements provide proper context for learning" (p. 14). Whatever students learn in the classroom should be easily related to their real world experience. Stein (1998) summarizes factors to consider when developing classroom experiences using situated theory as follows:

1. learning is grounded in the actions of everyday situations;
2. knowledge is acquired situationally and transfers only to similar situations;
3. learning is the result of a social process encompassing ways of thinking, perceiving, problem solving, and interacting in addition to declarative and procedural knowledge; and
4. learning is not separated from the world of action but exists in robust, complex, social environments made up of actors, actions, and situations (Stein, 1998).

Savery and Duffy (1995, p. 38) proposed eight instructional strategies to satisfy constructivism and situated learning as follows:

1. Anchor all learning activities to a larger task or problem.
2. Support the learner in developing ownership for the overall problem or task.
3. Design an authentic task.
4. Design the task and the learning environment to reflect the complexity of the environment they should be able to function in at the end of learning.
5. Give the learner ownership of the process used to develop a solution.
6. Design the learning environment to support and challenge the learner's thinking.
7. Encourage testing ideas against alternative views and alternative contexts.

8. Provide opportunity for and support reflection on both the content learned and the learning process.

Problem-based learning can be understood through the constructivist lens because the activities encourage learners to actively participate, use their pre-existing ideas, challenge their ideas through investigations, and interact with phenomena (Burris, 2005). Situated learning theory practices are also manifested in PBL because activities come from real world experiences and social interactions are encouraged. In PBL, students work on a problem, and the activities are designed to support and challenge learners' thinking. Furthermore, PBL encourages students independence by supporting learners in developing ownership of their learning (Savery, 2006).

Theory of Planned Behavior

Attitude and SEB constructs are described by the Theory of Planned Behavior (TPB) (Ajzen & Fishbein, 1977). This theory is centered on the individual's "intention to perform a given behavior" (Ajzen, 1991, p. 181). Intentions determine the level of willingness to try something and the amount of effort that an individual is ready to commit towards accomplishing an activity (Ajzen, 1991). Only those with strong intentions to engage in a behavior are likely to perform it. Performance of a behavior also depends on the individual's ability to control it. Behavior control does not only depend on motivational factors but also on the availability of requisite opportunities and resources such as time, money, skills, etc. (Ajzen, 1991). An individual having both intention and resources is likely to succeed in performing a behavior.

Three independent determinants: attitudes, subjective norms, and perceived behavioral control, predict intentions in TPB. Ajzen (1991) defines attitude towards a behavior as “the degree to which a person has a favorable or unfavorable evaluation or appraisal of the behavior in question” (p. 188). He defines the second predictor, subject norms, as “the perceived social pressure to perform or not to perform the behavior” and perceived behavior control as people’s perception of “the ease or difficulty of performing the behavior [that] is assumed to reflect past experience as well as anticipated impediments and obstacles’ (Azjen, 1991, p. 188). Individuals with more positive attitudes, subjective norms, and behavior control generally have high intentions of performing the behavior. The influence of each of the three constructs mentioned above vary depending on the behavior and situations.

Perceived Behavioral Control

Perceived behavior control is a very important predictor of intention and therefore among the core parts of TPB. Ajzen (1991) defines perceived behavior control as “people’s perception of the ease or difficulty of performing the behavior of interest” (p. 183). This view of perceived self control is concomitant with Bandura’s (1977; 1982) concept of perceived self-efficacy where individuals judge the extent to which they can execute courses of action in response to various situations. Research by Bandura and others has shown that confidence in an individual’s ability to perform tasks results in the accomplishment of those tasks (Bandura, Adams, & Beyer, 1977; Bandura, Adams, Hardy, & Howells, 1980). Thus, SEBs can determine what individuals choose to perform, how they prepare for the performance, and what their reaction would be after performing the activity (Bandura, 1982).

This study is an interaction between constructivism and social theory and, hence, will provide information on how the application of a constructivist teaching approach

(PBL) influences students' planned behavior (attitudes and self-efficacy beliefs).

Why PBL, Attitudes, and Self-Efficacy Beliefs?

The NSTA (2004) position on science learning requires students to accomplish the following (http://www.nsta.org/about/positions/inquiry.aspx):

- Learn how to identify and ask appropriate questions that can be answered through scientific investigations.
- Design and conduct investigations to collect the evidence needed to answer a variety of questions.
- Use appropriate equipment and tools to interpret and analyze data.
- Learn how to draw conclusions and think critically and logically to create explanations based on their evidence.
- Communicate and defend their results to their peers and others.

Problem-based learning as an instructional tool has been able to effectively respond to the NSTA's requirements because it includes all the stages outlined above. True to the above assertion, research has shown that PBL has learning outcomes that include improving critical thinking (Iwaoka, Li, & Rhee, 2010), conceptual understanding (Dinem, & Balim, 2010; Pease & Kuhn, 2010), and performance in the classroom (Gurpinar *et al*., 2005). Most of this research comes from the medical field because the medical field was among the pioneers in utilizing PBL in instruction. Science in general also joined the bandwagon to investigate more about PBL. Most studies focus on the connection between PBL and classroom performance, critical thinking, and the students' views about the instructional approach (Alessio, 2004; Tarhan & Acar, 2007). This study will extend understanding of the influence of PBL on the affective domain.

Why Chemistry?

Chemists are involved in producing a range of products from soaps to medicines to polymers. Chemistry is a vital part in biology, material science, pharmacology, medicine and health, and other sciences. Due to chemistry's involvement in many other fields, it presents many opportunities to incorporate real world experience which involves solving challenging problems. PBL can be an important tool when teaching students problem-solving because this instruction mimics real-world experience. Also in the traditional laboratory classes in chemistry, students perform teacher-structured exercises or experiments (Kelly & Finlayson, 2007). These cookbook laboratories do not encourage students' thinking, which is necessary for real-world applications.

Furthermore, chemistry is perceived to be a difficult subject although it has important real-life applications (Sirhan, 2007). This is because it contains many abstract concepts that are precursors to continuing with chemistry and other related subjects, such as biology (Taber, 2002). Too much abstract content overloads students' working memory, creates language and communication difficulties, prevents concept formation, and diminishes students' motivation to pursue chemistry (Sirhan, 2007).

Another reason is that students' views of a discipline are context-dependent. For instance, students who harbor positive perceptions about biology or physics might not have similar feelings for chemistry (Schwartz & Bohner, 2001). Even closely related disciplines such as physics and chemistry have different aims for instruction and hence occur in different contexts (Bishop, 2004). Therefore, developing instructional methods with the potential to improve SEBs in and attitudes towards chemistry must be one of the main goals of chemical education. Thus, this study is a stepping stone towards accomplishing that goal.

The Present Study

The PBL activities were developed by a co-researcher (Current, 2014) for general chemistry laboratory classes at a Midwestern university in the USA: CHEM 1 and CHEM 2. These activities were aligned with research being conducted by faculty in the chemistry department of the host university and hence strengthen their authenticity. Two units were developed: pesticide sensors and biodiesel. The sensor unit activity required students to investigate the effectiveness of sensors to identify pesticides on food items while the biodiesel unit asked them to investigate optimum conditions for the production of biodiesel. The activities were planned for four laboratory sessions of three hours each. Students underwent a cooperative active learning process that involved solving an ill-structured problem. This involved reviewing literature provided as handouts, proposing a research question, designing an experiment to answer the question, doing self-directed learning while conducting experimental trials, writing a research report, and presenting to the class. This study aimed at determining the changes that occur in attitudes and self-efficacy beliefs after undergoing PBL activities because they are integral to students' learning (Akınoğlu & Tandoğan, 2007; Dehkordi & Heydarnejad, 2008). A mixed methods design has been used for data collection to optimize the advantages of both quantitative and qualitative research.

CHAPTER 2

LITERATURE REVIEW

Introduction to Problem-Based Learning

Among the learner-centered approaches being adopted recently is problem-based learning (PBL). PBL has its roots in constructivism because it incorporates instructional strategies as proposed by Savery and Duffy (2001). According to Barrows (1988), PBL is a constructivist educational approach where curriculum and instruction are organized around carefully crafted ill-structured problems. In this approach, teachers act as cognitive coaches to develop students' critical thinking, problem solving, and collaborative skills (Ram, 1999). The wisdom behind PBL is to bring relevance to students' learning and enable them to appreciate the complexity of real-world problems. It develops skills that facilitate development of creativity and responsibility in students because they take control of the whole process with minor assistance from their teachers. The characteristics above align with what Hung (2002) outlined as the instructional aims of situated learning. Hung (2002) reported that students in situated learning should be actively involved in their learning process, and the instructor's role must be facilitation. In addition, activities in situated learning must mimic reality. Therefore, PBL satisfies both constructivist and situated learning instructional approaches. This is in contrast to lecture methods where teachers dominate and learners take a passive role in their learning.

The term problem-based learning emerged in the late 1960s at McMaster University in Canada, where it was used by Barrows and Tamblyn (1980). Initially, PBL was mostly used in medical schools before being adopted by fields such as chemistry, biology, and engineering (Barrows & Tamblyn, 1980; Du & Graaff, 2009; Ram, 1999). Practices from various fields indicated marked differences in how educators in each field implemented PBL. This brought confusion about whether PBL should be defined based on specific practices or common principles (Du & Graaff, 2009).

Models of PBL

The earliest form of PBL was characterized by several key elements. Students worked in small teams to explore a situation and identify their deficiencies in knowledge regarding solving the problem at hand. The classic model of PBL, according to Barrows and Tamblyn (1980), comprised the following steps:

- Students identified a complex real world problem that was supposed to have no right or wrong answer.
- Students confronted the problem in small groups through discussions, which led to gap identification and development of viable solutions to resolve the problem.
- Students had an opportunity to conduct self-directed learning where they used information from different sources as they confronted the problem.
- Instructors provided guidance as students worked on their problems.

Although different models have been proposed for PBL, in all these models the center is the problem (Pease & Kuhn, 2010, Hmelo-Silver, 2004). This implies that the focus of the different forms of PBL is solving an ill-structured problem. This problem can be addressed in cooperative learning groups (Hmelo-Silver, 2004) or at the individual level (Pease & Kuhn, 2010). Conway and Little (2000) suggest that PBL can assume two different forms: as an instructional strategy or as a curriculum design. As an instructional strategy, PBL can be incorporated into an existing program as a teaching method for one topic, module, or component of a program. In curriculum design, it is a philosophy of an institution, such as McMaster University, that utilizes an integrated approach to both curriculum design and learning (Degraffs & Kolmos, 2007). In this case, the whole curriculum is composed of problems that need solutions. As students process information to determine these solutions, they learn the required knowledge and skills. Others classify PBL into two categories: the pure model and the hybrid model (Brinkley, 2011). The pure model utilizes PBL throughout the instructional process while the hybrid model mixes PBL activities with other teaching approaches such as lectures and tutorials. Currently, most programs are implementing the hybrid PBL because it does not require a comprehensive change to the whole curriculum and therefore is easier to incorporate (Brinkley, 2011; Degraffs & Kolmos, 2007).

Pure PBL is not generally appropriate for all situations due to a number of factors. These factors relate to class size, number of facilitators, and curriculum designs. Therefore, different institutions and classrooms implement PBL to suit their situations (Brinkley, 2011). Amongst the models, the following stand out. The *medical school* model makes the whole curriculum PBL. Classes solve ill-structured problems throughout the curriculum with little or no use of other methods such as lecture. This model is suitable for small classes and needs a sufficient number of tutors to accomplish its goals (Brinkley, 2011; Malan, 2008). Normally, this model has more than one facilitator with the goal of having a single facilitator for each group. Each group in this model contains about eight to ten students with one student chairing the group.

For large classrooms, the *floating facilitator* model is often used because it is almost impossible to have a single tutor for each group (Malan, 2008). This model usually has smaller student groups than the medical school model; each group has about four to five students. The tutor walks around the class guiding the groups as they discuss their problems. In other situations, some students with higher capability and skills are used to mentor their classmates in their respective groups through a PBL model known as the *Peer Tutor Model*. This model has the potential to improve confidence amongst the students who mentor others and at the same time encourage the other students to get involved in their discussions (Brinkley, 2011). Peer tutors give feedback which enables instructors to improve their models. The *Large Class Model* is similar to the floating facilitator model, except that it usually has more than one tutor. This is appropriate for a large class and normally uses either undergraduate peer tutors or graduate teaching assistants as facilitators. Usually, teachers generate questions and moderate discussions among the groups. Often times, moderators limit the discussion time within each group and ask probing questions to generate meaningful discussions (Brinkley, 2011; Malan, 2008).

Regardless of the model used, however, there is a general agreement that a successful PBL instruction must have the following steps:

The problem. The instructor presents a problem or scenarios to the students (Duch, 2001; Hmelo & Ferrari, 1997). The students read through the problem to understand what they are seeking.

Discussion of the problem. Confronted with the problem, students determine what they already know about the problem and what information is missing and needs to be researched. Once students establish what is known and unknown, they create their learning goals and determine how to proceed (Belt, Evans, McCreedy, Overton, & Summerfield, 2002; Hung, Jonassen, & Liu, 2008).

Research. Most PBL groups share responsibilities amongst individual members. One way is to give each student a specific objective to do research on or to let all students study the same objective independent of each other. This ensures that everyone is fully involved in the activities. Sometimes groups ask each individual to investigate similar pertinent issues within a single group and divide non-pertinent issues amongst individuals in the group. Students then embark on their respective self-directed investigations. These typically start with literature review through reading journals, books, websites (Belt et al., 2002; Hung et al., 2008). Sometimes they visist experts, or use other resources to collect information (Hung et al., 2008).

Results analysis. Whether in groups (Belt et al, 2002; Hung et al, 2008) or as individuals (Pease & Kuhn, 2010), students analyze their results. Whenever necessary, students rewrite or refine their methodology and embark on further research to buttress their initial findings. This continues until satisfactory results are obtained. How long students repeat the data collection process depends on the complexity of the problem, time, and other factors. This enables students to apply newly acquired knowledge through the discussions to their investigations (Hung et al., 2008).

Solution generation, presentation, and evaluation. During the results group analysis phase, students generate solutions to their problem. To make more accurate generalizations, they sometimes rely on what is already in the literature and other research materials. Once they get their solutions, they make a written report or an oral presentation to make their solution public (Hmelo-Silver, 2004). Figure 1 summarizes the PBL steps.

The PBL activities for this study included all the steps outlined in Figure 1. The instructor presented a problem to students and guided them through a discussion that resulted in research. During the discussion stage, the problem was broken into sub-problems. Apart from reviewing literature during the research stage, students also performed experiments to answer the problem. After generating solutions to the sub-problems, students presented their results and their feedback was collected as part of evaluation of the PBL process.

PBL Versus Guided Inquiry

There is a strong connection between guided inquiry and PBL. Hansen (2003, p. 35) defines “Inquiry” as follows**:**

> Inquiry refers to the work scientists do when they study the natural world, proposing explanations that include evidence gathered from the world around them. The term also includes the activities of students—such as posing questions, planning investigations, and reviewing what is already known in light of experimental evidence—that mirror what scientists do.

According to the National Research Council (2000, p. 23) “Inquiry requires identifying assumptions, use of critical and logical thinking, and consideration of alternative explanations.” Amongst the different types of inquiry is guided inquiry, where instructors guide students to become actively involved in the instruction process.

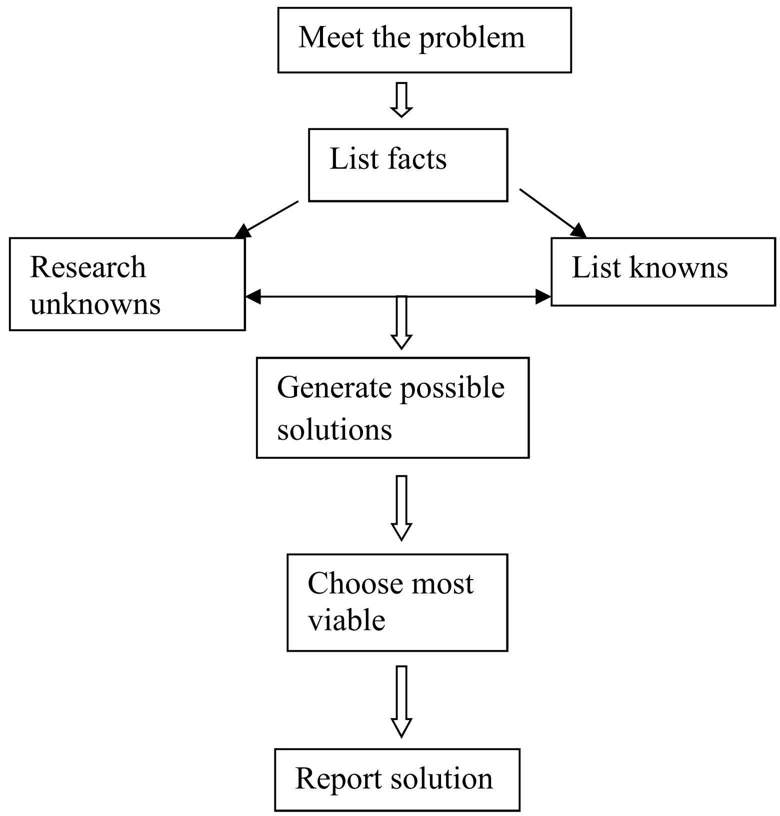

Figure 1. Steps in PBL

The instructor proposes questions for investigations, and students, with the instructor's guidance, develop plans for investigation within large or small groups. Problem-based learning has a similar structure to guided inquiry because the instructor also proposes questions for investigation and students plan their investigation with instructor's approval. Further, students conduct self-directed research using sources either from their instructors, libraries, the internet, and sometimes experts. During the discussion sections, students explore various alternatives to understand their problem and its solutions (Belt, Evans, McCreedy, Overton, & Summerfield, 2002; Hung, Jonassen, & Liu, 2008). All these processes are reflected in the definitions of inquiry by the National Research Council (2000) and Hansen (2003). Therefore, this confirms the assertions that

PBL is a form of guided inquiry. Although there is a strong connection between guided inquiry and PBL, this dissertation focuses on PBL alone.

PBL and its Influence in Education

Studies have been carried out to determine the influence of PBL in education. Some of the studies investigated the influence of PBL on higher-order skills such as problem solving, critical thinking, and conceptual learning. The review below will discuss a theoretical and empirical perspective of these influences.

PBL and Higher-Order Skills

One goal of education is to teach higher-order thinking to students so that they are effective members of society (King, Goodson, & Rohan, 1998; Ramirez & Ganaden, 2008; Roth, 2010). Higher-order thinking is reflected in the upper part of Bloom's taxonomy: analysis, synthesis, and evaluation (Ramirez & Ganaden, 2008). These skills include critical, logical, reflective, metacognitive, and creative thinking (King, Goodson, & Rohan, 1998). The skills are applicable when dealing with novel and unfamiliar situations. Individuals who successfully apply these skills are usually good at explanations, decision-making, solving uncertainties, and other capabilities within the context of their knowledge and experience (King et al., 1998). To promote higher-order thinking skills, educators should use appropriate teaching strategies to foster students' growth, persistence, self-monitoring, and open-minded and flexible attitudes. Various authors have encouraged active teaching/learning as a way of promoting development of higher order thinking skills (King et al., 1998; Ramirez & Ganaden, 2008). The argument above indicates that individuals with higher-order thinking ability are creative, good problem solvers as well as good critical thinkers. This section reviews literature pertaining to the influence of PBL on two higher-order thinking skills: (1) problem solving and (2) critical and creative thinking.

PBL and problem solving: Theoretical perspective. Among the lifelong learning skills that students need to acquire is problem solving (Jonassen, 2010). Jonassen (2010) claims that problem solving is the ultimate goal of education because (1) learning is intentional, (2) the knowledge is more relevant to the learners, and (3) it is easier to retain knowledge that was used in an authentic environment. According to Hayes (1980), a problem occurs "whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap." Therefore, discovering this 'way' is an important part of problem solving. From these definitions, Bodner (1991) categorized problems into two groups: those that we do routinely as exercises and those that are new as problems. Jonassen (2011) also classifies problems into different categories. The first of these is story problems. Story problems need students to identify key values and select and apply the appropriate algorithm from a story. Usually, these problems have a single path and a single answer. Problems with multiple paths and a single answer are Rule-using/Rule-induction Problems. These problems have a clear goal that can be attained using various routes, e.g. how to study for an exam. Then we have higher level problems such as decision making problems, strategic performance problems, design problems, policy problems, and dilemmas. All of these problems are ill-structured and have multiple pathways and multiple solutions. Sometimes there are multiple criteria to evaluate the solutions.

Presently, employers, educators, and funding bodies have put emphasis on programs that develop a wide range of subject-specific and transferable skills during university courses (Belt, Leisvik, Hyde, & Overton, 2005). These groups of society agree that universities should produce graduates who are able to work with novel problems and plan strategies for their solution, interpret chemical information, and present scientific arguments. This shows that problem solving is critical to both academic and professional practice, especially for complex, ambiguous, novel, and conflicting situations (Gabr & Muhamed, 2011). Both academic and professional education programs are increasingly incorporating and emphasizing solving ill-structured problems into their curricula (Gabr & Muhamed, 2011; Gallagher et al., 2011). Nickerson (1994) argued for emphasis on effective and purposeful problem solving. Visser (2002, p. 2) reiterates Nickerson's (1994) argument that problem solving is "(1) at the core of the survival of individuals and communities interacting with an increasingly complex external environment, (2) essential to developing and sustaining a democratic society, and (3) an increasingly sought-after high level cognitive ability in the knowledge workplace of today."

PBL can be applied using different approaches that include case studies, worked examples, structured analogies, and alternative perspectives. Therefore, when executing PBL, educators must think about the purpose and the problem that needs to be solved. PBL also is one possible strategy that advocates group collaboration and encourages problem solving (Belt et al., 2005). PBL is aimed at "the development of problem solving skill, self-directedness, and technical knowledge (knowledge of facts, concepts and rules) in a professional area" (Belt et al., 2005). Students in PBL have an opportunity to work with authentic problems through several steps used to solve ill-structured problems. The assumption is that when students solve problems like those encountered in real life, they are likely to improve their ability to solve various types of problems.

PBL and problem solving: Empirical evidence. Chin and Chia (2006) found that the use of ill-structured problems in PBL elicited desirable successes in students' cognitive processing that are essential for good problem solving. Students were able to formulate research problems, pose questions, design and conduct investigations, make explanations, and propose alternative ideas through brainstorming. They argue that students who make their own decisions about the direction of their study, what information to collect, and what analysis and evaluations to make can easily accommodate a variety of learning styles. This is possible because PBL provides opportunities for alternative ways to attain a solution for their problems. PBL usually encourages “self-directed learning, active engagement, generalization, multiplicity of ideas, reflectivity, personal relevance, and collaboration” (Chin & Chia, 2006, p. 64). These attributes, combined with solving ill-structured problems, prepare students for real world challenges (Chin & Chia, 2006).

Yalcin, Karahan, Karadenizli, and Sahin (2006) investigated short term effects of PBL on students’ scientific thinking, problem solving, and conflict resolution skills at two medical schools in Turkey. One university followed PBL while the other one used a lecture approach. The experimental group consisted of 83 first-year students from the PBL university, and the control group had 124 first-year students from the didactic university. Both groups completed the Problem Solving Inventory, Scientific Thinking Skills Questionnaire, and Conflict Resolution Scale prior to and after 10 months of instruction. Although there was no significant difference between the two groups in the pre-test, the experimental group performed better at scientific thinking, problem solving, and conflict resolution ($p < 0.001$) during the post-test. This study concluded that PBL may have a positive impact on the scientific thinking, problem solving, and conflict resolution skills of students.

Another study by Gabr and Mohamed (2011) compared the influence of PBL on undergraduate nursing students' knowledge, self-directed learning, and problem-solving ability at Mansoura University, Egypt. Results indicated that the control group performed significantly better ($p < 0.000$) on the knowledge test (m = 35.7 vs. 33.5) than the PBL group. 84.6% of control group versus 57.6% of treatment group acquired grades rated good and very good ($p < 0.05$) on the knowledge test. The PBL group performed significantly better ($p < 0.000$) on the problem solving skills test (m = 35.1 vs. 30.2) and the Self-Directed Learner Readiness Scale (m = 162.9 vs. 150.6) than the control group. In terms of problem solving, 69.3% of the PBL group acquired a grade of good and above versus 30.8% of the control section. From their results, Gabr and Mohamed (2011) concluded that PBL had clear benefits in that it increased self-directed learning and problem solving skills.

In another study, Klegeris and Hurren (2011) used PBL cases as an instructional strategy for large biochemistry and biology classes (approximately 80 students per class) facilitated by a single instructor. The study had two main objectives: "(1) to measure improvements in problem-solving skills due to exposure to PBL and (2) to assess students' perception of PBL as a teaching methodology that was implemented in a large class setting without the use of tutors" (p. 2537). This study took place at the University of British Columbia Okanagan (Canada) and involved students taking Pharmacology I in 2010 and Pharmacology II in 2011. Klegeris and Hurren (2011) sandwiched their PBL sessions into traditional lecture classes by substituting some lecture sessions (80 minutes each session) for the PBL classes. In total, there were two cases each semester covering three sessions per case (at least one week apart), which makes PBL delivery 25% of the classes. Results from this study indicated that students using PBL had better responses to problems and had better plans for solving their problem than the control group.

PBL and critical thinking: Theoretical perspective. Facione (1990, p. 2) defines critical thinking as a "purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as an explanation of the evidential, conceptual, methodological, criteria, logical or contextual considerations upon which judgment is based." Students need to be taught the ability to evaluate situations before developing resolutions. Critical thinking skills are a tool for this purpose because students are taught to evaluate arguments and resolve conflict using well-reasoned processes (Allegretti & Frederick, 1995). Lipman (1988) and Sternberg (1990) developed guidelines for instructors who intend to teach critical thinking.

According to Sternberg (1990), students will effectively learn critical thinking skills when instructors focus their teaching on mental processes, translating the mental processes into action, and using previous knowledge to understand the present information. Strengthening the mental processes will enable students to plan, monitor, and evaluate situations. This shows that PBL can also influence students' metacognition, which deals with planning for self-learning (Lin, 2001). After planning, students should be able to carry out their plan and determine what previous knowledge to use to achieve their goals. Thus, proper learning experiences are required to sufficiently instill these critical reasoning skills. Sternberg (1990) claims that we need to look outside of our traditional instruction style if we have to improve critical thinking in our students.

Lipman (1988) agrees with Sternberg, adding that the focus must be on teaching the students skills to explain their reasoning using evidence. To this end, Lipman (1988) encourages teachers to clearly understand what critical thinking is before considering instruction. This will enable them to plan appropriate instructional techniques using suitable materials. Lipman (1988) further recommended that teachers must be role models as critical thinkers to their students. The way they ask questions, clarify statements, and solve problems will reflect on their students' view of these processes. Important cognitive skills include interpretation, analysis, evaluation, explanation, and self-regulation among others (Facione, 1990).

Students who have good critical thinking skills are purposeful in their discussions and are able to self-regulate themselves in the learning environment (Masek & Yamin, 2012). Presently, emphasis in instruction is on directing a student on what to think instead of teaching him/her how to think (Daud & Husin, 2004). Recent authors acknowledge that there must be a major change in instructional paradigm to facilitate approaches that encourage students' use of their thinking abilities (Behar-Horenstein & Niu, 2011). Instructors must accommodate these new strategies in the disciplinary content (Behar-Horenstein & Niu, 2011) to ensure that more students access them.

PBL is one technique that fulfills most of the skills proposed by Facione (1990). In PBL, students' activities are geared towards enabling them to develop meaning from the instructional process. In this case, students acquire knowledge by thinking through the activities that they undertake (Hmelo-Silver, 2004; Winterton et al., 2006). PBL deals with real-life ill-structured problems that are often complex (Uden & Beaumont, 2006).

The process of solving these problems is also complex, requiring students to use their mental capacity to develop solutions (Uden & Beaumont, 2006). Students have to interact with both colleagues and materials that lead to use and refinement of critical thinking skills (Iwaoka et al., 2010). For instance, effective problem solving needs students to identify and define a problem, interpret the problem, devise a plan to deal with the problem, carry out the plan to solve the problem, get results, and analyze and interpret the results. These processes are similar to those involved in the critical thinking skills as proposed Facione (1990). Therefore, theoretically, use of PBL has the capacity to improve students' critical thinking (Hmelo-Silver & Ferrari, 1997; Savery, 2006).

PBL and critical thinking: Empirical evidence. A number of authors have investigated the influence of PBL on students' critical thinking skills. The review presented here will demonstrate conflicting results: positive change, no change, and negative change. Choi (2004) investigated the impact of PBL on nursing students at Konkuk University using a pre/post test with the California Critical Thinking Skill Test (CCTST) Form 2000. A repeated measure and correlation analysis indicated that there was no significant difference between the pre-test and the post-test. Furthermore, Choi (2004) found that there was no relationship between problem solving and critical thinking using correlation analysis. Another study (Polanco, Calderon, & Delgado, 2004) also found no significant difference between the PBL and control groups of first and second year engineering students doing math and science from Mexican universities. This study used an instrument similar to that used by Choi (2004) to measure critical thinking skills.

Recently, Masek and Yamin (2012) compared the influence of PBL and conventional approaches on first year engineering students' critical thinking using a modified Cornell Critical Thinking Test Specimen (CCTTS) as a pre- and post-test. This test measures how students' reason based on their ability to use induction, deduction, and other elements of reasoning. Results from this study indicated that there was no significant difference ($F = 1.47$, $p > 0.05$) between the PBL and the conventional groups. Masek and Yamin (2012) argue that their results were not compatible with those of comparable studies (Hmelo-Silver & Ferrari, 1997; Savery, 2006) because this study investigated first year students who might not completely discard the thinking behind their previous conventional instruction. These results are supported by Sulaiman (2011) who used the treatment-control group design to investigate the influence of PBL on the following critical thinking skills: inference, assumption, deduction, and interpretation on tertiary-level physics students. They measured students' critical thinking using the Watson Glaser Critical Thinking Appraisal Forms A and B. Generally, there was also no significant difference between the conventional and PBL group. However, the traditional group performed significantly better on their understanding of 'assumption' ($t = -2.09$, $p = 0.04$) while the PBL group performed better on 'inference' ($t = -3.30$, $p = 0.00$). These contrasting results overshadow a proper conclusion about the influence of PBL in critical thinking. However, Sulaiman (2011) believes that given sufficient time, students may improve their critical thinking with PBL.

Pursuing this further, an eight year study by Iwaoka et al. (2010) found conflicting results. This study was conducted among food science and nutrition courses within the period 2001 to 2008, and critical thinking was evaluated using the Cornell Critical Thinking Test (CCTT). The critical thinking skills evaluated were deduction, meaning, observation, assumption, and induction. Data from 2002 and 2004 indicated that students using PBL performed significantly better on deduction (2002: $t = 2.19$, $p = 0.024$; 2004: $t = 2.24$, $p = 0.020$) and assumption (2002: $t = 1.85$, $p = 0.045$; 2004: $t = 1.93$, $p = 0.036$). Data from the other years did not show any significant change. Iwaoka et al. (2010) provided two explanations for the two years of significant results. They suggest that it's either chance or that students within those years were more receptive to the PBL. However, this still demonstrates that their data is inconclusive.

A study by Sendaq and Odabasi (2009) used a treatment-control design to investigate the influence of online PBL in computer science education. The mean critical thinking scores improved for both the treatment (66.50 – 75.05) and the control groups (66.45 – 70.30). The analysis of pre- and post-test results indicated that there was no significant difference in critical thinking between the treatment and the control section ($F_{(1, 39)} = 1.98$; $p = 0.168$). Nevertheless, a two-way mixed design ANOVA showed that students in the treatment section had better progress in their critical thinking than those in the control section ($F_{(1,38)} = 4{:}848$; $p = 0.034$). The authors of this study recommended online PBL over conventional online learning to improve critical thinking skills. They advised instructors to evaluate which sections of their courses can be easily taught using PBL instead of using the approach wholesale.

Derry et al. (2000) qualitatively investigated the influence of a PBL course in fostering students' scientific and statistical thinking. The PBL activities involved solving simulated problems similar to those found in the real world. They used interviews at the beginning and after the PBL activities to determine whether there were any changes in the way students reasoned. Their aim was to determine whether or not students increased statistical arguments and decreased non-statistical arguments in their reasoning. This study found that the use of statistical arguments improved while the use of non-statistical arguments decreased after the course. This indicates that PBL had an impact on the students' statistical arguments which is core to critical thinking.

PBL and Conceptual Learning

The reviews in this section indicate that students taught through PBL have higher conceptual understanding than their counterparts. Bilgin, Senocak, and Solzbir (2008) used a non-equivalent pre-test/post-test control group design to investigate the influence of PBL on both the conceptual and quantitative understanding of gas concepts by university students. The Conceptual Problems Gases Test (CPGT) and Quantitative Problems Gases Test (QPGT) were used as test items for conceptual and quantitative understanding respectively. Results from this study indicated that the PBL group outscored ($p = 0.02$) the control group on the conceptual tests but performed similarly ($p = 0.239$) to their counterparts on the quantitative problems. However, the mean performances of these two groups on conceptual knowledge (14.05 and 12.55) indicated a slight difference.

In another study, Tasoglu and Bakac (2010) also investigated the effect of PBL on students' conceptual understanding about work and energy using the open-ended version of "The Work-Energy Unit Achievement Test." Students enrolled in this study graduated from two distinct high schools with different mean performances on their university entrance exams. During the pretest, one high school significantly outperformed the other but this difference was eliminated after undergoing PBL instruction. Results from the control group showed that the students from the lowest performing high school did not close the conceptual understanding gap during the posttest. These results agree with

Sahin (2010) who found that students taught using PBL had a higher ($p = 0.001$) conceptual understanding of Newtonian mechanics than those taught using lecture. This is an improvement from the results that Sahin and Yorek (2009) obtained previously. Similarly, Yadav, Subedia, Lundeberg, and Bunting (2011) investigated the influence of PBL on conceptual understanding of undergraduate electrical engineering students from a Midwestern US university. They found that the PBL students had an average gain twice that of the lecture group. These gains were both statistically ($p < 0.001$) and practically (Cohen's $d > 0.75$) significant.

In addition, Pease and Kuhn (2010) conducted a within-subject design to investigate the effect of using PBL on undergraduate students' conceptual understanding of the physics terms electrical and gravitational force. They found that students in the PBL section had significantly higher conceptual understanding than the control group. In chemistry, Barak and Dori (2005) used PBL learning to enhance students' understanding of chemistry concepts through a treatment and control group analysis. These students were enrolled in a freshman chemistry course at the Israel Institute of Technology. Using an analysis of covariance (ANCOVA), the treatment group significantly outperformed the control section on both the post-test ($p < 0.01$) and the final exam ($p < 0.02$). This study also investigated the ability of students to traverse through the four levels of chemistry understanding: symbolic, macroscopic, microscopic, and process. In this respect, the PBL group also had a significant upper hand ($p < 0.001$). PBL students were easily able to recognize the formula (symbolic), describe properties of substances (macroscopic), develop explanations at the molecular level (microscopic), and properly balance chemical equations for the reactions (process). These authors showed that PBL enhanced students' performance in chemistry. During the same period, Alcázar and Fitzgerald (2005) investigated how college chemistry students taught through PBL accomplish tasks capturing various stages of Bloom's taxonomy using a control treatment group study. This study found that the control students had a significant upper hand on lower levels of Bloom's taxonomy. However, the PBL group performed significantly better than the control group on higher order skills of the Bloom's taxonomy: analysis, synthesis, and evaluation.

Self-Efficacy Beliefs

Bandura (1986, p. 391) defines self-efficacy beliefs as "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances". This construct deals with people's judgement about their capabilities and not on the skills that they posses. Self-efficacy was propagated by Bandura (1977) in his unifying theory of behavioral change. In this theory, he discussed cognitively-based sources of motivation to set and achieve specific goals. According to Bandura (1977), people who are self-motivated set up standards against which to evaluate their performance and strive to realize those goals.

Four major sources are responsible for the development of self-efficacy (Bandura, 1977; Strecher, DeVellis, Becker, & Rosenstock, 1986). Individuals who develop self-efficacy through personal experience use the 'performance accomplishment mastery experiences route' while those learning it through observations of other people or events use the 'vicarious' approaches. The last two are verbal persuasion and one's physiological and affective state.

In mastery experiences, individuals improve their SEBs after accomplishing tasks.

This route seems to be one of the most effective approaches to developing positive SEBs because individuals realize that they can accomplish previously difficult tasks. Mastery of tasks also helps in the development of strategies to cope with difficulties encountered on the way (Strecher et al., 1986). This probably enhances confidence in individuals because they know what they are capable of accomplishing. Grunert and Bodner (2011) found that the mastery component of SEBs helped determine the career paths of female chemistry graduate and undergraduate students. For instance, students who had more positive teaching experiences than research experiences felt they would be better teachers than researchers. One student felt she could make a good faculty member because she developed a research project and was published. She felt she had mastered what professors do and so was confident she could do the same. Typically, development and improvement of SEBs is a result of a combination of all four sources.

Verbal or social persuasion is necessary when individuals need to be convinced that they are capable of accomplishing their goals (Bandura, 1986). To be effective, the person who is persuading must be regarded as sufficiently competent by the receiver. A study by Zeldin and Pajares (2000) demonstrate the effectiveness of persuasion self-efficacy. These authors investigated the influence of persuasion on women's SEBs towards mathematics. Family members, teachers, peers, and supervisors provided cues encouraging the women about their ability in mathematics. Of the 15 women who participated in interviews, 10 reported that a family member encouraged them to take a mathematics career path. Some women indicated that peers were supportive of their mathematics major or career choice. This mentioned the women's confidence in themselves. Grunert and Bodner (2011) also found that female students overcame their negative experiences in chemistry with the help of social support.

Individuals can also develop positive self-efficacy beliefs through vicarious experiences after observing other individuals do particular tasks or acts (Bandura, 1997). These observations influence how individuals become confident of their abilities. Noble (2011) found that African-American male students loved mathematics after becoming motivated by their teacher. For instance, one student mentioned that his pre-calculus teacher in junior high school was motivating, which motivated him to excel in mathematics.

Physiological and affective state deals with arousal cues that may lower or improve an individual's SEBs (Bandura, 1986). These cues include previous experience, social stereotypes, and conditions under which the arousal occurs. Steele and Aronson (1995) argue that groups that are stereotyped or under-represented may develop anxiety in their activities. For instance, Kelly (2007) found that female students' mathematics achievement decreased after introducing a stereotype threat to them. Meanwhile, Kiefer and Sekquaptewa (2007) found that implicit gender stereotyping negatively correlated with desire to pursue a mathematical career for women. However, Kiefer and Sekquaptewa (2007) demonstrated that once the stereotype threat is removed women's performance in mathematics improved. This study found that when less emphasis was put on gender identity, women's performance in math improved.

Self-Efficacy Beliefs and Cognitive Processes

Bandura (1986) believed that higher SEBs may improve cognitive processes for individuals. For instance, individuals with high SEBs set higher personal goals and commit to those goals. Individuals with higher SEBs construct higher standard scenarios, which lead to innovation. Bandura (1993) argues that "people's beliefs in their efficacy influence the types of anticipatory scenarios they construct and rehearse" (p. 118). In this case, the success of the scenarios depends on the individual's SEBs.

Self-efficacy beliefs are also very crucial because, as Bandura (1993) revealed, human ability is not static but changes with the proper reorganization of cognitive, social, motivational, and behavioral skills. Furthermore, individuals need to develop a tough skin for managing difficult situations, which may hinder the development of proper thinking capabilities. Given the same task, individuals can perform with different vigor and commitment depending on the fluctuations of their SEBs although they have similar knowledge and skills. Thought process requires individuals to make predictions about events and how they can control them. High SEBs are required to properly go through this process and accomplish the goals that individuals set for themselves (Bandura, 1993).

Self-Efficacy and Academic Motivation

Studies have established a connection between SEBs and student learning characteristics. A positive correlation has been established between SEBs, academic motivation, effort, and persistence to do activities and react to situations (Zimmerman & Lebeau, 2000). Bandura (1997) showed that students with positive SEBs had greater participation, worked harder, and were more resilient than those who had a negative view of their capabilities. In another study, Bandura and Schunk (1981) found that students with higher SEBs were more ready to work on difficult mathematical problems than their counterparts with low SEBs. These results were corroborated by Zimmerman and Kitsantas (1997) who investigated the influence of SEBs on the intrinsic interest of motoric learning tasks and a writing revision task. Results from their study suggested that students who had positive SEBs had a higher intrinsic interest in these skills than their counterparts. Other studies have also indicated that students with higher SEBs in a discipline are likely to major within that area (Hackett & Betz, 1989; Lent, Brown, & Larkin, 1984). Betz and Hackett (1983) conducted a study to determine whether mathematics SEBs correlated with the choice of a science major in college students. Their results indicated a significant correlation between students' math SEBs and their choice of college major.

Success in education requires considerable effort from both students and instructors. Self-efficacy beliefs have been shown to positively correlate with effort in solving arithmetic problems (Schunk & Hanson, 1985; Schunk, Hanson, & Cox, 1987) and performance in understanding readings of a difficult text (Salomon, 1984). In their investigation about the relationship between self-efficacy and motivation, Chowdhury and Shahabudd (2007) found a positive significant correlation. The correlation was significant for both intrinsic ($r = 0.490$) and extrinsic ($r = 0.297$) motivation at $p < 0.01$.

Self-Efficacy Measures and Academic Performance

A review of literature makes a compelling argument about why measurements of SEBs among students is important in education. A positive SEBs measure in itself may not help us understand its impact on students' learning. Correlation studies help researchers understand the influence of SEBs on students’ learning. Chowdhury and Shahabudd (2007) found a positive correlation between SEBs and students’ motivation. There was also a positive correlation between motivation and performance, which translated to a correlation between SEBs and academic achievement. Another study by Andrew (1998) also found a positive correlation ($r = 0.43$, $p > 0.001$) between students’

SEBs and their performance in two bioscience courses. Similarly, Ferla, Valcke, and Cai (2009) found that we can use students' SEBs to predict their academic achievement.

In another study, Jungert and Rosander (2010) investigated the influence of SEBs on students' study environment and its correlation with achievement. They found that higher achieving students had more positive ($F_{(2, 275)} = 6.49$, $p < .005$) SEBs than their lower performing counterparts. They also found that students who had lower SEBs were more likely ($F(2, 275) = 22.36$, $p < .001$) to harbor thoughts of quitting the engineering program than students with higher SEBs. These authors also found that both formal and informal factors can affect students' SEBs. They suggested that teaching approaches, like PBL, which use informal strategies for instruction may have an influence on students' SEBs. According to Jungert and Rosander (2010), students who are given a conducive learning environment are likely to improve their SEBs towards learning. These results concur with those of Kan and Akbaş (2006), who investigated the influence of affective factors towards achievement in chemistry. They found that high school students' SEBs in chemistry correlated positively ($r = 0.29$, $p < 0.01$) with their performance. Another study (Senay, 2010) also found similar results on 11th grade high school chemistry students in Turkey. This study investigated the correlation between chemistry SEBs and students' achievement. The study found that 9.1% of the variance in students' performance was explained by their efficacy beliefs towards chemistry ($R = .30$, $F_{(6, 597)} = 9.95$, $p < .05$). Performance is positively correlated to SEBs because students with higher SEBs are more resilient and work longer on difficult learning tasks than their counterparts (Bandura, 1977, 1982; Bandura & Schunk, 1981). All this suggests that educators need to devote more energy to teaching practices that positively enhance SEBs to realize students' full potential for learning.

Self-efficacy beliefs have also correlated with students' ability to self-regulate during learning. Martinez (2009) found a positive correlation ($r = 0.239$, $p < 0.001$) between SEBs and students' self regulation in computer studies. Bouchard, Parent, and Larivee (1991) found that students with higher SEBs were able to control their time better ($F_{(1, 81)} = 4.50$, $p < 0.05$) and were more persistent ($F_{(1, 81)} = 4.93$, $p < 0.03$) than those with low SEBs. In terms of performance, students with higher SEBs had more correct answers on their class work than those with low SEBs. These results are concomitant with Bandura's (1977) and Harter's (1983) beliefs that a perception of reality can have more influence on students' persistence to complete an activity than the reality itself. Bouchard et al. (1991) found that students who complete their activities are likely to have a higher score than their counterparts who do not finish. Therefore, the perception that enables students to accomplish their goals can also improve their performance.

Pursuing this further, Zajacova, Lynch, and Espenshade (2005) carried out a study to investigate the influence of students' SEBs and stress on college academic performance. This study had three correlates: (1) self-efficacy and stress, (2) grades, credits, and persistence, and (3) demographic factors and academic success. There was a negative correlation between stress and self-efficacy beliefs. Items that ranked high on anxiety level also ranked high on the self-efficacy beliefs scale. For instance, three items "writing term papers", "having more tests in the same week", and "doing well in my toughest class" were the most stressful, and students had less confidence in doing them. Correlation coefficients (range -0.26 to -0.74) between self-efficacy beliefs and stress were negative and significant ($p < 0.05$).

Learning Environments and Self-Efficacy

Bandura (1989) argued that efforts to develop students' self-efficacy beliefs depend on what school of thought one believes in. There are people who believe that cognitive skill can be improved. Those people will formulate activities that strive to accomplish this goal. People who believe that cognitive knowledge is inherent will not bother to improve it. Bandura (1993) argued that people's views about their ability to control their environments also influences their self-efficacy beliefs. People who believe that they can either change or modify their environment are likely to have higher self-efficacy beliefs than their counterparts who doubt their ability. This means that activities that enable students to experience environments with varying difficulty levels may be able to improve their self-efficacy beliefs. The authors reviewed above (Jungert & Rosander, 2010; Senay, 2010) claim that a conducive teaching/learning environment can foster the development of students' self-efficacy beliefs. Keller (1987, p. 5) proposed a learning environment that would foster the development of students' self-efficacy beliefs as follows:

- Teach students how to develop a plan of work that will result in goal accomplishment.
- Help students set realistic goals.
- Give verbal praise for successful progress or accomplishment.
- Provide motivating feedback (praise) immediately following task performance.

As Jungert and Rosander (2010) previously suggested, PBL is one of the strategies that has the potential to foster positive self-efficacy beliefs because the students set their goals and develop realistic plans to accomplish them. Furthermore, the activities that students encounter in PBL enable them to explore their abilities towards solving problems and applying classroom work to real world situations (Gabr and Mohamed 2011, Lohman et al., 2002; Yalcin et al., 2006). Moos and Azevedo (2009) found that students who had a behavior modeling computer experience had more computer self-efficacy beliefs than those who received traditional instruction. Ertmer et al. (1994) found that more use of computers did not improve undergraduate students self-efficacy beliefs, but the quality of the computer experience did. This shows that the quality of instruction is relevant for improvement of students' self-efficacy beliefs. Similarly, Nawang and Lago (2007) investigated the influence of cooperative learning on students' self-efficacy beliefs. They found that students who used the cooperative learning environment achieved higher ($p < 0.05$) self-efficacy scores than those who used lecture/discussion approach. These results affirm the need for a proper learning environment to enhance students' positive self-efficacy beliefs.

Attitude Development and Change

Students' perception and evaluation of their experiences within a discipline are important in their learning process (Bloom, 1979). Students need to show interest in the subject for them to commit themselves to understanding the learning activities within that discipline. Lindahl (2003) showed that students' decisions to study science were significantly correlated with their interest in science. Fairbrother (2000) believed that students can learn well only when they are willing to do so. Taltont and Simpson (1984) also argued that the students' attitudes towards science will determine whether they commit themselves to pursuing it or not. Instructors have a role to ensure that students' have a keen interest in science to improve outcomes of instruction. A study of students attitude towards science can be a good starting point.

Various authors have defined the term attitude in different ways. This indicates that there is not a single clear definition of this term. Koballa and Glyn (2007) reveal that authors usually use the term attitude interchangeably with other terms such as interests, beliefs, curiosity, and opinions. In their review of literature, Osborne et al. (2003) found that studies related to attitude towards science had titles like 'anxiety towards science', 'self-esteem towards science', 'motivation for science', and other affective terms. According to Gagne (1979), attitudes have a significant role in influencing the individual's choice. To him, attitude is a state of readiness that is acquired through experience and affects individuals' responses to situations. In simple terms, attitude relates to emotional responses to specific phenomenon such as a teaching approach, a course, or a location (Simpson & Oliver, 1990). These attitudes, therefore, can be developed within an individual through learning and may be modified using different learning/teaching strategies or exposure to new information (Adesina & Akinbobola, 2005).

Most literature relating to attitudinal studies about science is found in elementary, middle, and high school, with very few studies at the college level (Turkmen, 2007). A literature review by Cheng (2000) revealed that even in high schools very few studies about students' attitude towards science have been carried out. For instance, Hofstein et al. (1977) found that the attitude towards chemistry among Israel's 11^{th} grade students declined significantly when they entered 12th grade. A subsequent study in the USA (Menis, 1989) found that 12th grade students had a significantly more positive attitude towards chemistry than the 11th grade students. However, these studies used different instruments to determine students' attitude and the differences in instructional approaches were also not considered.

Similarly, Khan and Ali (2012) investigated high school students' attitudes towards chemistry. The focus was on attitude subscales, students' attitudes towards their chemistry teacher, students' attitude towards chemistry, and students' attitudes towards chemistry methodology. This study showed that students had positive attitudes towards their teacher. The students agreed that the teacher was easily accessible (3.83), highly motivating (4.75), and taught appropriate content for problem solving (4.4) on a five-point Likert scale. However, satisfaction with the teacher did not translate to their views about chemistry. The students had a neutral view about chemistry and most of them (65%) did not consider it to be fun. Likewise, Mochire (2010) found that Kenyan high school students had a neutral attitude towards chemistry. Among the attitude subscales, Mochire found that out of 1172 students surveyed, 54% enjoyed chemistry, 63% felt that the practical work was difficult, fewer students (24%) understood chemistry concepts quite well and felt that chemistry assignments were easy, and very few students (6.8%) gave chemistry more study time than other subjects. She recommended that teachers must develop ways to improve students' attitudes because this may have a positive impact on learning. In addition, Regan and Childs (2003) found that Irish high school students had a positive attitude towards both science and chemistry. In this study, students showed increased interest in chemistry because of college course requirements, and their feelings were that those who take chemistry have a brighter path to careers.

At the college level, Mogane (2010) investigated medical students' attitudes towards chemistry subgroups: practical classes, subject content, lecture classes, and chemistry as a discipline. Most students (65%) felt that the chemistry practical work was not useful to their profession. About half of the class felt that there was no proper relationship between what they did in the laboratory and their lectures. Some students (58%) did not like chemistry laboratories because they thought they were dangerous. About half of the students felt that chemistry lecture was not motivating or stimulating enough. They preferred tutorials (47%) to lecture because most concepts were not clearly explained during the lecture. Surprisingly, in this study, most students (70%) felt that chemistry as a discipline was relevant in medicine. However, most of them (69%) took chemistry because it was mandatory although they felt that it was a difficult subject. Nevertheless, they (51%) acknowledged that chemistry provided them some knowledge they would use in their clinical career.

Another study by Delgado and Rodríguez (2009) investigated the attitudes towards chemistry among engineering students pursuing a bachelor’s degree program at the Polytechnic University of Puerto Rico. Results from the study found that students had neutral views about the usefulness of chemistry to their engineering profession and other fields. The authors believed that students may not have clearly understood their profession and the need for chemistry in it, however, they felt that knowing chemistry was a necessity for every engineer. Although most students acknowledged the need to take chemistry, they felt that it was difficult and most of them responded negatively when asked about taking more chemistry courses. One important factor to note from this study is that students considered time and state of the laboratories as the major determinants of their attitude towards chemistry. Students also had a neutral attitude about their professor, textbooks, and course content as the source of their difficulty in chemistry.

From the interviews, students felt that the amount of time and the type of professor they had influenced their attitudes towards chemistry. The students also gave conflicting views about chemistry ranging from perceiving it to be very difficult to interesting. The interviewees also noted that laboratories were a very fundamental part of the discipline. They had a sense that chemistry is more experimental than the other science disciplines.

Classroom Environment and Attitudes

According to Lippman (2010), the learning environment has four components: the learner, other students, the teacher, and the physical environment. Recently, educators believed that learning environments must promote students to engage in self-directed and cooperative learning activities (Partnership for 21st Century Skills, 2002). Several studies have found that the learning environment plays a crucial role in determining the students' attitudes towards science. Myers and Fouts (1992) found that students had more positive attitudes in environments with sufficient level of students involvement, teacher support, better student-to-student interaction, and the use of innovation. Nolen (2003) found that encouraging students to be independent thinkers and helping them to have a clear understanding of scientific concepts also played a big role in their attitude towards science. In this respect, Myers and Fouts (1992) believe that instructors have a very important role to play in ensuring a positive learning environment. McRobbie and Fraser (1993) also found that integrating work between the laboratory and non-laboratory activities positively influenced students' attitudes towards science.

In chemistry, various studies have also shown the influence of a learning environment on students' attitudes towards the discipline. Okebukofa (1986) found that students improved their attitude towards chemistry after attending a chemistry laboratory class. The author believes that students' engagement in hands-on activities in the laboratory may have improved their skills and this improved their attitudes towards chemistry. From these results, Okebukofa (1986) suggested that instructors must strive to increase participation in classroom activities and become more resourceful to improve both motivation and attitude towards chemistry. Akcayi et al. (2006) showed that students who were taught using a computer-based environment had a significant change in attitude towards analytical chemistry than those taught using lecture. Using an in-depth analysis about the observed changes in their attitude towards chemistry, Anders and Berg (2005) found that students felt that contextual factors had a big role to play. The major factors responsible were "(1) perception of instructor behaviors, (2) perception of tasks, (3) perception of reward and goal structures, and (4) perception of instructional methods" (p. 10). All these factors underscore the significance of a proper environment to students' attitudes towards chemistry. Osuafor (1999) found that poor method of instruction was responsible for students' negative attitude towards chemistry. Other studies found that poorly planned laboratory activities (Akpan, 1986; Brotherton & Breece, 1996), inadequate science background (Bellow, 1985), and insufficient problem solving skills (Akpan, 1986) negatively affected students' attitudes towards chemistry.

Attitude and Academic Achievement

Correlation studies between attitude and achievement presented inconsistent results. Shih and Gamon (2001) investigated the relationship between attitude and performance in web-based science courses. Their study found no significant correlation between students' attitudes towards and performance in science. However, they believed that attitude could affect students' motivation towards web-based science. Motivation is important because it excites students to actively participate in their own learning. Hence, Shih and Gamon (2001) compelled instructors to adopt appropriate teaching/learning approaches to improve students' attitudes towards web-based science. Kinniard (2010) examined the influence of attitude on students' achievement in mathematics. This study also found no significant correlation between students' attitudes and performance in science. Nasr and Soltan (2011) correlated attitude and students' achievement towards biology. Their results found a small non-significant correlation ($r = 0.12$, $p = 0.08$) between the two constructs. However, there was a significant correlation ($r = 0.304$, $p = 0.00$) between the dimension 'Biology is fun for me' and achievement. These authors believe that making learning a fun activity may improve students' curiosity and make them work hard to enhance their performance. Evans (2007) also correlated attitude and achievement towards statistics. This study found a significant correlation ($r = 0.451$, $p = 0.018$) between students' attitudes and performance. Hence, Evans (2007) believes that attitude has an influence on students' performance. This observation means that even capable students may not perform to their capacity if they have a negative attitude towards their course.

In chemistry, Mogane (2010) found a significant correlation between students' attitudes and performance. Attitude towards chemistry was correlated with students' procedural and declarative knowledge. The correlation coefficients between attitude and procedural knowledge ($r = 0.485$, $p = 0.000$) and declarative knowledge ($r = 0.671$, $p = 0.000$) were both positive and significant. This indicates that students' attitudes may predict their performance in chemistry. This also concurs with Evans' (2007) observation that developing positive attitudes may enhance performance in students. An earlier study (Ewa, Mina, & Hermanus, 1999), also found a significant relationship between students' attitude towards chemistry and their performance.

Relationship Between Attitude And Self-Efficacy Beliefs

Studies have been conducted to determine the relationship between self-efficacy beliefs and attitudes. Li (2012) investigated the relationship between attitude towards research methods & statistics and academic self-efficacy. This study found that there was a moderate positive correlation between attitude and self-efficacy beliefs. A positive correlation ($r = 0.589$, $p < 0.001$) was observed between attitude towards research methods and academic self-efficacy beliefs. Another positive correlation ($r = 0.641$, $p < 0.001$) was observed between attitude towards statistics and academic self-efficacy beliefs. Perepiczka, Chandler, and Becerra (2011) also investigated the relationship between graduate students' statistics self-efficacy beliefs and attitudes towards statistics. They found a significant relationship ($r = 0.708$, $p < 0.001$) between self-efficacy beliefs in and attitudes towards statistics. Similarly, Yalcinalp (2005) found a positive significant correlation ($r = 0.436$, $p < 0.05$) between students' attitude towards computers and their self-efficacy beliefs. However, Yalcinalp (2005) found no correlation ($r = 0.189$ $p > 0.05$) between students' attitude towards using the internet and their internet self-efficacy beliefs. Yalcinalp's (2005) results contrasted with those by Wu and Tsai (2006), who investigated the relationship between university students' attitudes towards the internet and their internet self-efficacy beliefs. These authors found a positive significant correlation ($r \geq 0.32$, $p < 0.001$) and suggested that attitudes towards the internet could be an important predictor of students' internet self-efficacy beliefs. A similar trend was also observed in mathematics. Nicolidau and Philippou (2004) investigated the relationship between attitudes towards mathematics and students'mathematics self-efficacy beliefs. They found a positive significant correlation ($r = 0.44$, $p < 0.001$) between these two constructs, affirming their relationship. Another significant positive relationship ($r = 0.34$, $p < 0.05$) was observed between university students' chemistry laboratory attitudes and self-efficacy beliefs (Kurbanoglu & Akin, 2010).

All the studies above indicate that attitude can be used to predict students' self-efficacy beliefs and vice versa, hence instruction that improves one is also likely to improve the other. Literature reviewed earlier in this chapter indicates that both of these constructs also have a positive relationship with students' academic performance.

Effects of PBL on Students' Attitudes Towards Science

The study (Lindahl, 2003) quoted previously in this chapter regarded students' attitudes towards school subjects as one of the key factors in students' motivation to learn. Therefore, educators and instructors should devise ways to improve students' attitudes toward their disciplines. Although researchers have done a commendable job investigating the influence of PBL on several areas of learning, very little information is available about its influence on students' attitudes towards science and chemistry. Most studies in this realm were done at either middle school or high school levels (Turkmen, 2007; Cheng, 2000; Tamir, 1977). Very little information is available for college courses, although previous research has shown that attitude has a significant influence on learning science (Evans, 2007). The few studies conducted also seem not to have a rigorous approach to their research designs to give definitive conclusions.

Recently, Erdem (2012) investigated the influence of PBL on students' attitudes and anxiety towards science. Results from this study indicated that PBL did not have any effect on these two constructs, corroborating results from Langen and Welsh (2006). However, other authors (Akınoğlu & Tandoğan, 2007; Dehkordi & Heydarnejad, 2008; Chen & Chen, 2012) found conflicting results. Akınoğlu and Tandoğan (2007) found that students undergoing PBL had higher (m = 73.80) scores ($p < 0.05$) on an attitude survey than their counterparts (m = 65.60) who used lecture method. This indicated that these students improved their views about science after undergoing the PBL approach. Results from the attitude survey were also a reflection of the students' experiences during the PBL process. In this respect, most students felt that PBL scenarios taught them to answer scientific questions, helped them solve problems, and were generally fun. This demonstrates that students who take responsibility for what they are doing may be more motivated and hence improve their attitudes towards their activity or the discipline in general. These findings concur with those obtained by Dehkordi and Heydarnejad (2008) who also found that PBL improved students' attitudes towards science. Students who went through PBL significantly ($p < 0.05$) improved their attitude score compared to the lecture group. During the same time, Faris (2008) investigated the influence of PBL on high school students' attitudes towards science in Qatar. In this study, students worked on topics related to the environment and obesity. Data was collected using a questionnaire and reflective journals. Out of the 25 students who participated in the study, 22 showed a major improvement in their attitudes towards science. This was also attributed to the influence of PBL.

Other recent studies have also echoed findings from the previous research. Lou et al. (2011) found that hybrid PBL improved students' attitudes towards science, technology, engineering, and mathematics (STEM). The authors point out that PBL reveals students' capabilities through active participation. This in turn improves their confidence in pursuing science careers, which are regarded as difficult. Another study, Ferreira and Trudel (2012), used a pre-/post-test survey to investigate the influence of PBL on students' attitudes towards science. They found that students significantly ($p < 0.001$) improved their attitudes towards science after undergoing PBL instruction. More students agreed that science was important in critical and logical thinking and making good decisions than did not agree. There was also a reduction in the number of students who had a negative view about science during the post survey. The same authors found that students enjoyed taking more responsibility for their own learning and interacting with their colleagues through the PBL process. These factors were attributed to the improvement of the students' attitudes towards science. Similarly, Chen and Chen (2012) found that the use of PBL had encouraging outcomes on the attitudes of students towards science. These authors found that PBL approaches had a significant impact on several aspects of students' attitudes towards science, except career interest in science and enjoyment of science class. In their conclusion, Chen and Chen (2012) felt that the instruction method may affect the students' attitudes towards science and recommended that teachers develop instructional approaches that can effectively improve these attitudes.

Effects of PBL Toward Self-Efficacy Beliefs

Self-efficacy beliefs are important in education because they affect students' cognitive processes (Bandura, 1986), academic motivation (Bandura, 1997; Zimmerman & Lebeau, 2000), and academic performance (Ferla et al., 2009). The advantages of positive self-efficacy beliefs should encourage educators to research proper instructional approaches that can enhance this construct. The previous studies reviewed in this document have shown that PBL generally has a positive influence on students' performance, problem-solving abilities, critical thinking skills, and attitudes towards science, including chemistry. This section will show that PBL has also an influence on students' self-efficacy beliefs in science. However, the literature reviewed also has shown mixed outcomes from the use of PBL, with some showing a significant improvement (Liu, Hsieh, Cho and Schallert, 2006), while others (Konings, Wiers, Van de Wiel and Schmidt, 2005) showed no change.

To begin with, Konings et al. (2005) investigated the influence of a 9-week PBL unit on the self-efficacy beliefs of high school students with disabilities using a quasi-experimental split-plot design. The repeated measure design was used to collect data such that each individual had a pre- and a post-test score compared. In this study, self-efficacy beliefs were measured using the Dutch translation of the General Self-Efficacy Scale (GSES). Results from this study indicated that PBL did not improve (p = 0.32) students' self-efficacy beliefs towards geography education. This also corroborated with a decrease (p = 0.035) in students' learning self-esteem after participating in PBL. The authors believe that the time period was too short for any effects of PBL to be visible. They hoped that with time, students would get accustomed to PBL and its perceived uncertainty to really become more confident in themselves. Another study by Yiu, McGrath, Bridges, Cobert, Botelho, Dyson, and Chan (2011) compared the preparedness of two groups (PBL and lecture) of dental students for practice after graduation at the University of Hong Kong. Results from this study found no significant difference in the preparedness of these students in spite of their instructional approach. However, these students came from different cohorts that were about three years apart. Presumably, these differences might have a bearing on results from this study. Recently, Massa et al. (2012) found that the use of PBL improved the trend of students' self-efficacy beliefs in engineering. However, both statistical ($p = 0.632$) and practical ($d = 0.288$) tests indicated that the improvement was not significant. Nevertheless, data from interviews showed that the students had a more favorable view about their ability to solve real-world problems after PBL instruction.

In contrast, Liu et al. (2006) investigated the influence of computer-enhanced PBL on the science self-efficacy beliefs of middle school students. This study used both qualitative and quantitative approaches to determine the change in students' self-efficacy beliefs towards science. The quantitative data were collected using the GSES. Although the students in this group did not change their attitudes towards science, there was a significant difference ($F_{(1, 246)} = 12.61$, $p < 0.001$) between pre- and post-test on their self-efficacy scores. There was also a positive relationship ($r = 0.28$, $p < 0.001$) between self-efficacy beliefs and performance. Results from this study indicated that self-efficacy beliefs had a significant contribution to students' performance. This implies that instructional techniques that improve self-efficacy beliefs may enhance students' performance.

These results agree with those by Greg (2003) who investigated the change in students' perspectives about their confidence in self-directed learning after PBL instruction. In this study, PBL significantly ($p < 0.05$) improved the students' confidence to engage in self-directed learning. Greg (2003) believes that a good learning environment is vital for a significant change in students' confidence in themselves. Another study by Vazquez (2008) investigated the effects of PBL towards high school students' preparedness for college. Students in this study came from three categories, each with its own instructional approach: PBL, outreach service, and college center access. This study showed that students from the PBL approach had a significant improvement on some items of the self-efficacy instrument, but the author did not report the aggregate findings for this instrument. The general trend, however, indicated that the PBL students had the highest score on the self-efficacy instrument.

At the college level, Rajab (2007) used a pre- and post-test treatment control group design to investigate the influence of PBL on college students' self-efficacy beliefs in biology. The results from this study indicate that students who were taught through PBL had significantly higher self-efficacy beliefs and attitudes towards biology. Rajab (2007) attributed this improvement to students' opportunities to assume ownership of their learning, deep understanding of knowledge, and their feeling that the PBL approach was relevant in their future life. Dunlop (2005) investigated the influence of PBL on undergraduate students doing computer science at a Midwestern university in the USA. This study found that students became more confident about working in the IT world after participating in PBL and showed a significant ($t_{(30)} = -27.88$, $p < 0.000$) improvement in their software development self-efficacy beliefs. However, more information is still needed at college level to fully understand the influence of PBL on students self-efficacy beliefs.

Chapter 2 Summary

The PBL instructional approach involves students actively solving ill-structured problems with an instructor's guidance. The literature has shown that PBL has specific steps that can be applied in various ways depending on the problem and aim of the PBL. For instance, in the medical field PBL usually constitutes the whole curriculum. In other fields, PBL is generally implemented on specific topics within a traditional syllabus or in specific courses while the rest follows the traditional approach. Central to PBL is the ill-structured problem, hence PBL instruction may involve students working either individually or in groups. Studies from this section have generally indicated that PBL has a positive influence on students' higher-order skills. These skills include problem-solving and critical-thinking. A positive relationship was also observed between PBL and conceptual understanding. This indicates that PBL has a positive influence on students' cognitive abilities.

The chapter has also shown that self-efficacy beliefs originate from four sources, which include mastery, vicarious, verbal, and social and physiological state. Each of these sources of self-efficacy beliefs has an impact on education (Grunert, 2011, Noble, 2011, Pajares, 2000). Bandura (1986) indicated that self-efficacy beliefs have a positive relationship with cognitive processes because human abilities change due to the re-organization of cognitive, social, motivational, and behavioral skills. Some studies have also indicated a positive correlation between self-efficacy beliefs, academic motivation, effort, and persistence to do activities and react to situations (Betz and Hackett, 1983;

Zimmerman & Lebeau, 2000). There has also been a positive correlation between self-efficacy beliefs and academic achievement (Chowdhury & Shahabudd, 2007). Lastly, studies have also shown that learning environments have important implications for students' self-efficacy beliefs.

Further, this chapter has also shown that attitudes are amongst the most important predictors of students' interest in learning (Lindahl, 2003). Effective learning occurs only when students are willing to learn (Fairbrother, 2000). The studies in this paper show that most students have neutral views about chemistry (Mogane, 2010; Delgado & Rodríguez, 2009). Generally, attitudes had a positive correlation with classroom performance (Evans, 2007, Mogane, 2010), classroom environment (Myers & Fouts, 1992; McRobbie & Fraser, 1993), and self-efficacy beliefs (Li, 2012; Perepiczka et al., 2011).

Studies in other disciplines have shown that PBL has a positive relationship with students self-efficacy beliefs and attitudes (Dunlop, 2005; Liu et al., 2006). However, there is a dearth of information on the relationship between PBL and college chemistry students' attitudes and self-efficacy beliefs. Therefore, the purpose of this study is to determine the changes in attitudes and self-efficacy beliefs that occur when students learn chemistry through PBL laboratory. The students' views of the PBL learning environment will also be investigated.

CHAPTER 3

METHODOLOGY AND PROCEDURE

Introduction

This chapter describes the methods that were used to collect and analyze data. These include study design, data collection, processing, and analysis procedures. Consent processes have also been discussed. This is a convergent mixed method study where participants from two general chemistry classes at a Midwestern university in the USA participated in PBL activities. The aim of the study was to determine whether or not there was a change in students' attitudes and self-efficacy beliefs after participating in PBL activities. Another goal of the study was to investigate the students' views of the PBL environment. Instruments that measure attitudes, SEBs, and students views of the PBL environment have been used to collect the quantitative data. Semi-structured interviews have been used to collect the qualitative data. Paired-sample t-tests, independent t-tests, ANOVA, correlations, and regression analyzes have been used to interpret the quantitative data while an emergent coding model has been used for the interview data. The detailed description of the data analysis procedure is given below.

Subjects

The subjects in this study were students enrolled in either of two general chemistry laboratory courses (CHEM 1 & 2) at a Midwestern university in the USA. These students came from different backgrounds with different majors. This study occurred in Fall semester of 2012 (CHEM 1) and spring semester of 2013 (CHEM 2).

CHEM 1 and CHEM 2 had five and six PBL sections respectively. Chemistry graduate teaching assistants taught all these sections, coordinated by the instructor of record. Sensors and Biodiesel units were developed as PBL units for CHEM 1110 and CHEM 1130, respectively. The development of these PBL units has been thoroughly described by Current (2014). Each PBL unit took 4 laboratory sessions (4 weeks) towards the end of the semester. The number of students in each laboratory class ranged from 15 to 24. Most of these students had already taken at least one chemistry course in high school and most had taken at least one chemistry course in college. The gender distribution of the students was approximately 61% male and 39% female. Participants who volunteered to take part in this study were (1) registered in CHEM 110 or CHEM 1130, (2) enrolled in one of the PBL sections, and (3) signed a consent form.

The participants were recruited on the first day of PBL instruction. A consent form was read asking all students to complete a Chemistry Attitude and Experiences Questionnaire (CAEQ) and a PBL Learning Environment Inventory (PBLEI). During the same period, student volunteers were solicited for participation in interviews. Participants signed the consent form and the CAEQ pre-test was distributed and completed in class. On the last day, after class presentations, students completed the CAEQ post-test and PBLEI. Each student participant involved in the analysis had a paired score of pre- and post-test on the CAEQ survey for analysis and a single post-test score on the PBLEI survey. The recruitment of participants and data collection procedures were approved by the Human Subjects Institutional Review Board (HSIRB). Ninety-three percent of students completed all the surveys in CHEM 1 and 85% completed them in CHEM 2.

Fifteen participants volunteered for interviews and were interviewed at a quiet place convenient for both the interviewee and the interviewer. The interviews were conducted at the end of each PBL session. Semi-structured interview questions were used with the aim of determining how the students felt about PBL by determining the attributes that led to their views of the PBL environment. The second aim was to corroborate and expand upon the findings from the CAEQ and PBLEI through the interview questions. In this case, the aim was to determine whether students felt that they improved both their SEBs and attitudes after undergoing PBL instruction. The participants interviewed came from the Spring 2012, Summer 1 2012, Fall 2012, and Spring 2013 semesters. The data from the first two semesters constituted a pilot study. However, the qualitative data from these two semesters was included in the main study to ensure that enough data is available for qualitative analysis. Only participants who completed all the surveys for quantitative data collection were invited for interviews. The interviews were audio-recorded and transcribed verbatim by the researcher. Tables 1 and 2 summarize the data collection procedures for the quantitative section. (add mor information on interviewse.g. structure audio recorded etc

Table 1

Data collection table

Section	CHEM 1	CHEM 2
1	17	24
2	17	15
3	20	18
4	22	20
5	15	17
6	-	16
Total	91	110

Table 2

Volunteers for interviews

Spring 2012**	Summer 1 2012	Fall 2012*	Spring 2013**
Oliver	Dakota**	Steve	Cherie
Christine	Jessie*	Frank	Jacob
Tom	Sydney*		Lucas
Harry			Daniel
			Isabel
			William

*CHEM 1; **CHEM 2

Instruction Process

In CHEM 1, students investigated the effectiveness of sensors in identifying pesticides in food items. This activity was intended to help students learn about how chemical sensors work, what instruments are used to detect the colors, and how to design experiments. The sensors used in this activity were able to detect only three specific pesticides, hence students understood the implications of their results with regard to the presence or absence of specific versus all types of pesticides.

During the first day of instruction, students read articles about the pesticides and answered questions from the article. A discussion, which culminated in students developing their research questions for investigation, followed. Later, each group of students developed a research plan for the second laboratory day. On the second day, the proposed research plan was executed with the instructor’s guidance. Any challenges faced were discussed and improvements suggested for the third laboratory day. On the third day, students repeated their second day experiment with necessary changes or wholesale revisions to improve or affirm their results. The last day was for presentations and reflections.

In CHEM 2, students optimized the laboratory-scale production of biodiesel from fatty acids. During the first day of instruction, students were given handouts containing general factors that affect the production of biodiesel such as temperature, concentration of the reactants, and type of catalyst. They established optimum conditions of temperature, concentration, and type of catalyst for the production of Biodiesel. The instructional process was identical to the one described above for the sensors topic.

The Instructors

Graduate teaching assistants (GTAs) served as instructors for these classes, supervised by one faculty member familiar with PBL. These GTAs underwent an informal on-the job training through weekly discussions with a co-researcher. This informal training involved assisting the GTAs in familiarizing themselves with skills of inquiry such as questioning techniques that include probing and wait times and involving students in their own learning process. This training started at the beginning of each semester before the PBL topics and any changes in instructor behavior were followed and improvements suggested. This helped improve the GTAs ability to facilitate the PBL instructional technique. The teaching experience was observed through audiorecording of the instructors and making suggestions whenever necessary. Table 3 shows characteristics of the research group.

Purpose of the PBL Units

The purpose of the PBL units in these laboratory classes was to develop students' ability to solve ill-structured problems and appreciate the applications of chemistry in real-life situations. Studies have shown that the use of PBL generally improves students' problem solving (Chin & Chia, 2006) and conceptual understanding (Pease & Kuhn, 2010), amongst other advantages. However, this study focused on the changes in the

Table 3

Characteristics of the PBL groups

Student characteristics	CHEM 1	CHEM 2
GPA range	3.4 – 4.0	2.2 – 4.0
ACT score range	24 - 32	15 - 34
Student major	Biomedical sciences, Biology, Biochemistry, Chemistry, and Engineering.	Biomedical sciences, Biology, Biochemistry, Chemistry, and Engineering.
No. of chemistry courses	1 - 5	1 - 5
Instructor pseudonyms	Joseph, Norma, John, Jeff	Agatha, Norma, Jeff
Gender	Male: 53 Female: 34	Male: 57 Female: 36
Number of sections	5	6
Laboratory class	Gen CHEM I	Gen CHEM II
PBL topic	Sensors	Biodiesel

affective domain (attitudes and self-efficacy beliefs) that occur in students who undergo PBL chemistry laboratory experience. Previous studies have shown positive correlations between students' perceptions of their learning environment, self-efficacy beliefs (Ertmer et al., 1994; Moos & Azevedo, 2009), and attitudes (Akcayi et al., 2006; Okebukofa, 1986). Therefore, improving students' attitudes and self-efficacy beliefs may encourage students to enroll in future chemistry courses.

Research Design

The overall research design is a pre-experiment (the one group pretest/posttest design) with mixed data sources (Borg & Gall, 1983; p. 657; Creswell, 2002). The study seeks to determine students' changes in attitudes toward and self-efficacy beliefs in chemistry after learning through PBL laboratory units. A concurrent (convergent) mixed methods design was used as the research methodology (Fetters, Curry, & Creswell, 2013). This design involves collecting and analyzing both quantitative and qualitative data within a single study to obtain a deeper understanding of the problem (Creswell, 2002). This design is based on the assumption that neither quantitative nor qualitative designs give a full picture of the problem and its analysis, hence the need to combine both to complement each other (Green, Caracelli, & Graham, 1989, Tashakkori & Teddlie, 1998). The qualitative data in this study were collected after the quantitative data only for convenience purpose but could as well have been collected concurrently. The mixing was done only at the interpretation stage to ensure triangulation of the data sources (Greene et al., 1989; Creswell et al., 2003).

While ideally, concurrent mixed methods recommend equal weighting between quantitative and qualitative data, in practice, one data collection method is usually given more weight than the other (Creswell et al., 2003). In this study, quantitative data will form the core of this study and the qualitative data will provide data for triangulation (Creswell et al., 2003). Quantitative data was obtained through the previously mentioned surveys: CAEQ and PBLEI. The role of the quantitative section was to provide information about the extent by which the PBL instructional approach influenced students' attitudes towards and SEBs in chemistry. It also provided information on students' views of the PBL environment and the correlations between SEBs, attitudes, and views of the PBL environment. The quantitative part used one group pre-/post-test analysis of data. This study involves three steps: (Borg & Gall, 1983; p. 657)

(1) administration of a pre-test measuring the dependent variable,

(2) application of the experimental treatment to the subjects, and

(3) administration of a post-test measuring the dependent variable again.

This test is appropriate whenever an intervention is designed to influence a behavior that is very stable such as attitudes (Borg & Gall, 1983). Furthermore, this quantitative research design was necessitated due to lack of a credible control group to compare with the treatment group. For instance, the PBL groups studied topics not related to the ones done in non-PBL groups. Furthermore, in one semester the PBL group was composed of honors students while the usual labs group had regular students. These two reasons made it difficult to include non-PBL sections as control groups. Therefore, in this study the researcher investigated relationships instead of comparing teaching approaches and interpretation, and conclusions have been made within the confines of this design.

The qualitative data has provided information about students' experiences with the PBL environment. This phase of data collection was necessary to support the results of the quantitative surveys. Data from the qualitative phase has been used to provide a deeper understanding of students' chemistry attitudes and self-efficacy beliefs. From this data, the researcher intended to obtain a clearer picture for the observed responses in the quantitative section. Hence, this triangulation of data was intended to enhance the interpretation of the quantitative data and add a deeper understanding to the research results. Convenience sampling has been used in this study because the participants are in a specific course, using a specific teaching method.

Instrumentation

Chemistry Attitude and Experiences Questionnaire (CAEQ)

This instrument was developed by Dalgety, Coll, and Jones (2003). The CAEQ was intended to measure attitudes, self-efficacy beliefs, and learning experiences of first-year chemistry students. It is a 7-point Likert scale instrument developed using the Theory of Planned Behavior (TPB), with an adaptation to measure both attitude and self-efficacy beliefs. This instrument was validated by a panel of experts and student representatives from the intended population. The experts (chemistry faculty and graduate students) answered semi-structured interview questions pertaining to the instrument subscales, items, and a choice of questions. The instrument has three subscales: "attitude toward chemistry, chemistry self-efficacy, and chemistry learning experiences, with subscales derived from definitions of attitude, self-efficacy, learning experiences, and chemistry culture" (Dalgety et al., 2003, p. 656).

To validate the instrument, undergraduate chemistry students were interviewed extensively to establish clarity and relevance of the items. From these interviews, the self-efficacy part of the survey revealed two subscales for chemistry knowledge: learning chemistry theory self-efficacy and applying chemistry theory self-efficacy. Two other subscales for chemistry skills were revealed: learning chemistry skills self-efficacy and applying chemistry skills self-efficacy. The instrument was pilot tested by administering it to 129 first-year chemistry students at an institute in New Zealand. The attitude towards chemistry part of the instrument revealed six factors with a total of 22 items: “attitude toward chemists, skills of chemists (combined 8 items), attitude toward chemistry in society (4 items), leisure interest in chemistry (3 items), career interest (5 items), and chemists and the environment (a single-item subscale).” Factor analysis also confirmed the previous stated categories from the self-efficacy component of the instrument: “namely, learning chemistry theory self-efficacy, applying chemistry theory self-efficacy, learning chemistry skills self-efficacy, and applying science skills self-efficacy, with a high intercorrelation among factors” (Dalgety, et al., 2003, p. 657).

After making changes, a different group of first-year chemistry students from two other institutions in New Zealand was used to complete the validation process of the final version of CAEQ before (n = 332) and at the end (n = 337) of their chemistry courses. Factor analysis confirmed the subscales on the CAEQ from both the attitude and self-efficacy sections. At the beginning of the course the Kaiser-Meyer-Olkin (KMO) intercorrelation was 0.87 and increased at the end of the course to 0.90. Analysis of the self-efficacy scale indicated that the four factors suggested at the beginning collapsed to a single factor with KMO of 0.80. Cronbach’s alpha calculated at the beginning was 0.74 (n = 332) and 0.84 (n = 337) at the end of the course indicating that the instrument was appropriate to measure the intended behaviors. However, the authors recommended that the instrument be revalidated for use. Due to this, the instrument has been revalidated using the participants in this study using factor analysis.

This instrument has been used to determine changes in chemistry students’ attitudes and SEBs following PBL instruction. The third subscale, chemistry learning experiences, has not been used in this study. This instrument was selected because it was developed specifically for chemistry students and was properly validated. It was administered as a pre- and post-test and the researcher anticipated having both scores for each individual student to obtain the changes in scores. The scores for each individual were reported as the mean scores of the item score for each section of the instrument: attitude and SEBs. From this instrument the researcher intended to learn whether or not attitudes and/or SEBs had changed in the course of the PBL instruction, hence, use of the instrument has addressed research questions 1, 2, and 4.

Problem-Based Learning Environment Inventory

This instrument was constructed by Senocak (2009) to measure students' views of the PBL environment. The assumptions were that this instrument might measure a wide range of PBL activities and help educators appreciate students' views of the PBL activities. This instrument was also developed to assist curriculum developers in evaluating their PBL activities and making improvements as suggested by the students' views. Construction of this instrument was preceded by an extensive literature survey to determine what instruments were already in use and how this instrument could build on these previous ones. The stages involved in developing the PBLEI included "(1) item formulation, (2) content validation, (3) construct validation, (4) reliability calculation" (Senocack, 2009, p. 564). For stage 1 (item formulation), an extensive literature review about PBL learning was conducted. This review was used to provide a clear picture of high-quality PBL characteristics. From the literature, Senocak (2009) identified basic PBL activities such as (1) presentation of an ill-structured problem, (2) having an instructor to guide the metacognition process, and (3) having students work in groups to do collaboration activities.

Students (n = 387) evaluated the instructional environment using the final version of the PBLEI. Factor analysis was used to determine the construct validity by identifying which items enhanced the strength of the instrument. Suitability of data for factor analysis was determined using the Kaiser Meyer Olkin Test (KMO) and Bartlett's Test of Sphericity (Kaiser 1974; Bartlett 1954). Both of these tests showed that these items were suitable for factor analysis (Bartlett's $p = 0.000$ and KMO > 0.80).

Principal components analysis was carried out to determine the structure underlying the instrument, which indicated that items 26 and 28 did not adequately examine the required PBL constructs, and these were omitted from the instrument. Items 15, 18, and 25 had loading factors below 0.4 and were also removed from the instrument, leaving the final inventory with 23 items. The final inventory had 4 main subscales with different Cronbach alphas: teacher support (7 items, $r = 0.92$), students' responsibility (6 items, r = 0.80), students' interaction and collaboration (6 items, $r = 0.82$), and quality of the problem (4 items, $r = 0.84$). Analysis of the main categories indicated that the teacher support category accounted for 17.68% of variances, then the students' responsibility (13.86%), followed by student interaction and collaboration (11.40%), and then the quality of the problem (10.78%). In total the instrument explained 53.72% of the variability of the students' perception of the PBL environment. The reliability of the four categories (0.80 – 0.92) indicated that this instrument has a strong claim to its use in determining the PBL environment. George and Mallery (2001) describe this range as acceptable to excellent. This instrument has also beeen revalidated in this study.

This instrument has been used to investigate students' perceptions about the PBL environment. As with the CAEQ, this instrument was selected because it was developed specifically for science students and was properly validated. This instrument was administered as a post-test only. From this instrument, the researcher intended to learn whether or not students had positive views about the PBL environment and hence the instrument was intended to address research questions 3 and 4.

Interviews

The semi-structured interview protocol was developed by the researcher through a review of literature and discussions with the faculty advisor in this study. It contains 15 open-ended questions to investigate students' experiences with the PBL environment and their attitudes towards PBL. Interviews were integral to this study because they provided a deeper understanding of students' views of the instruction process through prompts and probing. Since interviews are a two-way conversation, participants were able clarify their responses and interviewers their questions. This enabled researchers to obtain subtle information that surveys could not capture. The interview addresses all four research questions. The interview questions are as follows:

1. What was your experience with the Problem Based Learning lab unit (labs where you solved a problem)?
2. How did your experience with PBL compare to your experience with non-PBL labs?
3. What did you learn from PBL? What did you learn from the regular labs?

   Prompts (problem solving, applications from real life)

   Think about specific skills such as

- Skills handling equipment.
- Skills posing relevant questions.
- What about the real world applications?

4. What did you like about the regular labs? What did you like about the PBL labs?
5. What was challenging about the PBL labs?
6. How did the PBL labs affect your views about
    - Chemistry and its roles in society?
    - Chemists and their roles in society?
7. How did the PBL unit affect your ability to plan and conduct experiments?
8. How did the PBL unit affect your interest and/or confidence in participating or conducting undergraduate research?
9. How did the PBL unit affect your interest and/or confidence in enrolling in future chemistry courses?
10. What suggestions do you have for improving the PBL labs?
11. What advice would you give to other students enrolled in the PBL labs?
12. Do you feel more or less confident about your abilities in chemistry as a result of completing the PBL laboratory unit? Why?
13. Are you more or less interested in chemistry as a result of completing the PBL laboratory unit? Why?
14. How has your attitude towards chemistry changed as a result of completing the PBL laboratory unit? What made your attitude change?
15. Would you be interested in participating in more PBL experiences? How likely are you to seek out other PBL experiences?

Data Analysis

A range of data analyses methods were used in this study, appropriate to the data collection methods, and this section presents the data analysis activities.

Factor Analysis

Factor analysis provides mathematical models to explain psychological aspects of human behavior and ability (Harman, 1976). The historical utilization of factor analysis was first observed from Charles Spearman's paper "General intelligence, objectivity determined and measured" published in the American Journal of Psychology in 1904. In its early stages, factor theorem was developed to identify a single factor from a set of variables. Spearman introduced a two-factor model that later gave birth to multiple-factor models that are being used today (Harman, 1976). Factor analysis' principle aim is to establish a small set of variables from a bigger set. This small number of categories, known as factors, is developed through correlating items "to attain scientific parsimony or economy of description" (Harman, 1976, p. 4).

Factor analysis is grouped into two types, exploratory (EFA) and confirmatory (CFA) factor analysis (Suhr, 2006). EFA is used to establish the underlying structure of data from a large data set. The researcher relies only on factor loading to uncover this underlying assumption. This is common when conducting initial validity tests of an instrument (Suhr, 2006). In CFA, researchers confirm the existence of relationships among observed variables and their underlying latent constructs (Suhr, 2006). Normally, the researcher has prior knowledge of the relationship from theory, empirical research, or both. Therefore, the researcher already knows the number of factors in a model and the items that load on each factor. Thus, the aim is to determine if the measures representing the variable really exist. This is done when confirming the validity of a previously validated instrument.

Revalidation of Instruments

The CAEQ and PBLEI were revalidated using the chemistry students participating in this study. A confirmatory factor analysis was conducted using SPSS to determine the factor loadings of items in each instrument. Item analysis was used to determine Cronbach's alpha. All this has been compared to the information presented by developers of these instruments. It was necessary to conduct this validation study because these instruments were constructed for a different population with a different purpose from the present study. For instance, the CAEQ was constructed to predict retention of chemistry students into the second year chemistry course while this study is determining attitude towards chemistry and self-efficacy beliefs in chemistry laboratory. Furthermore, this study is using only the parts of the whole instruments, hence the need for validation.

Significance Tests Between Means

A series of tests were conducted to determine appropriate significance tests to use. Kolmogorov-Sminorff tests were used to determine the normality of the distribution of scores for parametric tests. Kolmogorov-Sminorff tests give a KS Z coefficient and its significance level. Uniformly distributed data's probability level must be greater than the chosen alpha level for that data to be considered uniform.

As each participant had a CAEQ pre- and post-test score, paired sample t-tests were used to determine the level of difference between the mean scores of the whole

CAEQ attitudes or SEBs sections. A paired sample t-test is used when the performance of a single individual is followed through pre- and post-tests (Hinkle, Wiesma & Jurs, 1998). In this case, each student was expected to have a pre- and post-test score on the same test, necessitating the use of a paired sample t-test. This required dropping all students who did not have two scores on the CAEQ. The significance level of this study is $\alpha = 0.05$. Individual item analysis was also carried out to determine what items on both attitudes and SEBs scales had a significant change. This may also provide a clear picture on why, if any, there is attitudes or SEBs changes. The non-parametric Wilcox signed rank test for two related samples was used to determine the difference between mean scores of individual Likert items (Bertman, 2007).

Independent t-tests were used to determine the mean differences between participants in both pre- and post-test data of the CAEQ and PBLEI post-test. This analysis has assisted the researcher in determining whether or not there is a difference in attitudes, self-efficacy beliefs, and views of the PBL environment due to gender differences. Levene's test was used to determine the equivalence of variance of mean scores between male and female participants. Results from the independent t-test were intended to help in interpreting the changes in attitudes and self-efficacy beliefs, and students' views of the PBL environment.

Analysis of Variance

One-way analysis of variance (ANOVA) was used to determine the influence of confounding factors such as GPA, ACT scores, instructors, number of chemistry courses taken by the participants, and students' tentative college majors. The ANOVA was used to show whether or not at least one of the mean scores of these variables was different from the rest. However, to identify the actual means causing the difference, a Tukey's test was used as a follow up to the significant ANOVA test (Hinkle et al, 1998). This test measures whether or not the confidence interval of an individual mean amongst different mean scores includes zero. Inclusion of zero in the confidence level implies that the mean did not cause a significant difference while the opposite implies that the mean produced a significant difference. The ANOVA was intended to provide information that would help in interpreting the data because data interpretation must consider the influence of the confounding factors.

PBLEI Analysis

Descriptive analysis (means, standard deviation, and frequencies) were used to interpret the PBLEI survey. A mean instrumental score of three on the five-point Likert scale indicates a neutral view of the PBL environment. Therefore, a mean score of greater than three was considered a positive view of the PBL environment. Mean scores from different factors of the PBLEI were compared to determine how students' view varied with each instrumental variable and frequency tables were used to determine how many participants' scores were within the ranges of 1 – 2, >2 – 3, >3 – 4, and >4 -5. Percentages of participants for each range were calculated and used to interpret the discriptive data.

Correlation and Regression Studies

Simple and multiple pearson correlations were used to determine the relationship amongst the learning environment, students' attitudes, and students' SEBs. These studies were intended to help determine how each of the constructs being measured related with each other. The correlation coefficients were tested for significance at $\alpha = 0.05$. Multiple regression studies were conducted to establish a linear model of the relationship amongst these three variables. It was also intended to help determine the relationship between one construct and the other two constructs combined. Analysis of variance of regression (ANOVAR) was conducted to determine the significance level of difference from our expected models (Hinkle et al, 1998). Multiple correlation studies were also conducted to determine the relationship amongst students' responses from different sections of the PBLEI. This was intended to help determine how aspects of the PBLEI survey related to each other. Regression analysis was also intended to help establish a linear model amongst PBLEI sections. This linear model helped establish the influence of all the other factors to a selected factor from the PBLEI survey.

Qualitative Data Analysis

Interview respondents' demographic data such as gender, number of chemistry courses, and majors were recorded in a table to help with data analysis. The interviews were transcribed in Microsoft Word and identifiers were used instead of names to protect participants' identity. The interview transcripts were transferred to HyperResearch software for coding. Grounded theory was used for the coding process as proposed by Glaser and Straus (1967). In this coding scheme, the researcher never forces preconceived result (Glaser, 1992). The participants scripts are thoroughly read and data carefully reviewed line by line while assigning codes to apparent concepts (Bradley, Curry, & Devers, 2007). With further review, emerging codes are assigned to text that reflect the concepts that emerge. This culminate into developing specifications of codes and refining them to fit data (Bradley et al., 2007). Then a constant comparison is done on text with similar codes in roder to refine dimensions of the existing codes. In our study we followed this procedure and, hence, our codes evolved “inductively reflecting the ‘ground’, i.e. the experience of participants” (Bradley et al., 2007).

In our study, the participants’ scripts were thoroughly read as a way of immersing ourselves in the data to understand its meaning (Bradley et al. 2007). This provided a general picture from the transcripts and facilitated the initial identification of codes. Then the scripts were transferred to HyperResearch for detailed coding. The responses were entered into HyperResearch based on the question number on the interview protocol. Codes emerged from the trascripts and, with further review, these codes were assigned to text reflecting the concepts that emerged (Bradley et al., 2007). Constant comparison process was done on text containing similar codes to refine the coding process. All codes addressing similar issues were categorized into themes (Creswell, 1998). Interpretation of these themes were intended to provide information about students’ SEBs, attitudes, and views of the PBL environment.

Establishing credibility

In qualitative studies, researchers need to establish their trustworthiness and that of the data being presented (Eisner, 1991; Lincoln & Guba, 1985). There are no traditional validity and reliability methods for qualitative data other than a process of verification. Therefore, to establish credibility of the qualitative data, two individuals coded two interview transcripts together and agreed on the coding procedure. Then each individual coded 4 trascripts independently. The codes were mutually exclusive, hence the intercoder Kappa of 0.83 was found using SPSS, indicating strong agreement between the coders (Di Eugenio, 2000; Stemler, 2001). The differences were resolved between the two coders through discussion. The researcher coded the rest of the transcripts and then discussed the codes with the previous co-coder. Table 4 shows summarizes the data analysis procedure.

Research Permission and Ethical Considerations

Since human subjects are involved in this study, ethical considerations were given priority in accordance with regulations of the Institutional Review Board.

Table 4

A summary of data analysis for each research question

Research question	Analysis procedure
What changes in attitudes toward chemistry occur when students participate in a PBL laboratory unit?	• Paired sample t-tests to compare means between pre- and post-tests on attitude survey (CAEQ) • Interview quotes, codes, and themes
What changes in self-efficacy beliefs in chemistry occur when students participate in a PBL laboratory unit?	• Paired sample t-tests to compare means between pre- and post-tests on the self-efficacy survey (CAEQ) • Interview quotes, codes, and themes
What are the students' views of the PBL learning environment?	• Independent t-tests on mean scores between male and female participants on PBLEI • Multiple correlation between PBLEI factors • Linear regression amongst PBLEI factors • Interview quotes, codes, and themes
What is the relationship between students' views about the PBL learning environment and their self-efficacy beliefs in and attitudes towards chemistry?	• Multiple correlation between CAEQ attitude, CAEQ self-efficacy, and PBLEI surveys • Linear regression between CAEQ attitude, CAEQ self-efficacy, and PBLEI surveys • Interview quotes, codes, and themes

The researcher obtained permission from the WMU Human Subjects Institutional Review Board (HSIRB) to conduct this study. All considerations of students' confidentiality, informed consent, and students' motivators to participate were addressed in the HSIRB proposal. This study was approved in the expedited category because it did not pose any serious risks to students and involves adults. All data collection, data analysis, and dissemination procedures were conducted in accordance with HSIRB protocols.

The Role of the Researcher

The role of the researcher during the quantitative data collection encompassed identifying sample groups for data collection using standardized procedures such as convenience sampling, administering standardized surveys, and conducting reliability checks of the instrument. The researcher was also responsible for data analysis using rigorous statistical analysis procedures. During the qualitative data collection phase, the researcher conducted interviews, performed transcription, and analyzed the data. The researcher was not involved in the instruction process, which lessened the influence on students' responses during the surveys and interviews.

The researcher worked closely with the individuals responsible for developing the PBL activities. Therefore, he might have been inclined to hope for positive perceptions as a way to boost the PBL instruction. Also, previous studies have shown that PBL improved students' attitudes and SEBs in other disciplines. This might have led to a conception that the present study would show a similar improvement. These two reasons might be sources of bias on how the results of this study are viewed. To minimize this problem, verification procedures were instituted where an independent person listened to the interview recordings and compared them to the interview transcripts to ensure that the information matched. Also two independent individuals coded some of the interview transcripts and established intercoder reliability. Furthermore, triangulation of data from different sources reduced bias.

CHAPTER 4

RESULTS AND DATA ANALYSIS

Introduction

Chapter 4 presents the results and data analysis. The aim of the results and data analysis is to answer the four research questions as follows:

- What changes in attitudes toward chemistry occur when students participate in a PBL laboratory unit?
- What changes in self-efficacy beliefs in chemistry occur when students participate in a PBL laboratory unit?
- What are the students' views of the PBL environment?
- What is the relationship between chemistry students' views of the PBL environment, their self-efficacy beliefs, and their attitudes?

The chapter begins with instrumentation validation using factor analysis, then SEBs data and attitudes data within each semester. This is followed by the data on the students' view of the PBL environment. Then, data on the correlations and regressions amongst attitudes, SEBs, and students' views of the PBL environment is presented. Later, the qualitative data is presented. The qualitative data addresses the SEBs, attitudes and students' views of the PBL environment.

Teacher and Student Interactions

Generic interactions in the PBL environment were observed through audiotaping the instructors as they guided the students through the instruction. The interactions that were common amongst the instructors involved elicitation, prompting, and providing feedback (Current, 2014). It was observed that the learning process and the interactions involved transitioned from teacher-centered during the usual labs to student-centered during the PBL environment. These interactions were generic amongst all the PBL instructors.

Factor Analysis

Factor analysis was carried out to determine the suitability of our instruments for the study group. All the three instruments (CAEQ-attitude and self-efficacy, and PBLEI) were validated.

Self-Efficacy Beliefs Factor Analysis

Test For Suitability of the Data for Factor Analysis

Before conducting a factor analysis, tests must be conducted to determine suitability of the data for the factor analysis. Kaiser-Meyer-Olkin (KMO) and Bartlet tests have been used before (Dalgety et al., 2003) to determine suitability of the data for factor analysis. Hence, in this study we used the same tests to determine this suitability. For suitable data, the KMO coefficient must be greater than 0.6 while the significant level of the Bartlett's Chi-Square must be less than 0.05 (Williams, Brown, & Onsman, 2006).

Table 5 indicates a KMO value of 0.89 and an alpha value of 0.00. This indicates that our data is suitable for factor analysis.

Table 5

KMO and Bartlett's test SEBs data

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.889
Bartlett's Test of Sphericity	Approx. Chi-Square	1298.232
	df	55
	Sig.	.000

A confirmatory factor analysis with Varimax Rotation was done for the pre-test data. This data was taken from students doing PBL in Summer 1 and Fall 2012 semesters. From the factor analysis, two factors were dentified (Table 6). The two factors have been named confidence in conducting laboratory activities (7 items) and confidence in writing/summarizing chemistry activities (4 items). The factor analysis results for the SEBs section is slightly different from previously determined factors for similar items (Dalgety et al. 2003). Dalgety et al. (2006) reported that the SEBs section of CAEQ had only a single factor. This implies that this group had slightly different characteristics from the students in the first year chemistry course that the instrument was validated on.

The reliability of the Self-efficacy beliefs section of the instrument was also calculated to determine its suitability for this group of participants. The calculated Cronbach's alpha was 0.89 which is regarded as good (Tavakol & Dennick, 2011). Reliability of the individual factors was also calculated. Factor 1 had a reliability of 0.86 while factor 2 had the reliability of 0.82. This indicates that the SEBs section of the instrument is suitable for detecting small changes in students' SEBs of our study group.

Table 6

Factor analysis on the CAEQ SEBs section

Item	Conducting chemistry activities		Writing/summarizing chemistry activities	
		α		α
1	0.813			
2	0.728			
3	0.563			
4	0.737			
5	0.692			
6		0.86	0.814	0.82
7	0.521			
8			0.706	
9			0.852	
10	0.556			
11			0.578	
α-instrument		0.89		

Attitude Factor Analysis

Table 7 shows the KMO and Bartlett's tests for the attitude survey data. The KMO value is 0.87 and Bartlett significance is 0.00. This indicates that the attitude data is also suitable for factor analysis and can delianate small changes in students' views of the PBL environment.

Table 7

KMO and Bartlett's test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.866
Bartlett's Test of Sphericity	Approx. Chi-Square	2096.148
	df	171
	Sig.	.000

Table 8

Rotated component matrix for attitudes

Item no.	Components				
	CR	CA	CJ	CM	α
1	.453				
2	.611				
3	.562				
4	.496				0.79
5	.666				
6	.659				
7	.694				
8	.614				
9		.883			
10		.884			0.92
11		.822			
12		.841			
13			.823		0.71
14			.708		
15				.326	
16				.755	
17				.823	0.80
18				.746	
19				.715	
α			0.88		

Table 8 shows the item loadings. Items 9 to 12 loaded on factor one that was named *chemistry research (CR)*, items 1 to 8 loaded on factor 2 named *chemists are (CA).* The third factor had items 15 to 19 named *chemistry jobs (CJ),* and the fourth factor had two items named *chemistry media (CM)*. The Cronbach's alphas were 0.92, 0.79, 0.71, and 0.80 for factors 1 to 4, respectively, indicating suitability for this group. In addition, the whole instrument had a Cronbach's alpha of 0.88, which is regarded as good. This implies that the CAEQ attitude section is sensitive to small changes in attitudes. The factors obtained in this study are similar to those developed by the developer of the instrument. However, In this study, some factors were combined to form a single factor and other items were removed for lack of relevance. Hence, instead of six, four factors were observed.

PBLEI Factor Analysis

Table 9 shows the KMO and Bartlett's tests for environmental survey data. The KMO value is 0.90 and Bartlett significance is 0.00. This indicates that the views of PBL data is suitable for factor analysis.

Table 9

KMO and Bartlett's test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.898
Bartlett's Test of Sphericity	Approx. Chi-Square	2009.815
	df	210
	Sig.	.000

Table 10 shows the factor analysis of the 21 environmental survey items. Seven items loaded on factor 1, four items loaded on factor 2, six items loaded on factor 3, and four items loaded on factor 4. The names of the factors and the items within each factor were similar to those observed by the developer of the instrument (Senocak, 2009). The factors were named teacher support (TS), students' responsibility (SR), student interaction and collaboration (SIC), and quality of the problem (QP) respectively. The Cronbach's alphas ranged from 0.67 to 0.90. The highest alpha ($\alpha = 0.90$) was observed for factor 1, followed by factor 3 ($\alpha = 0.81$), then factors 2 (0.75) and 4 (0.75). For the whole instrument, the Cronbach's alpha was 0.91, indicating that small differences in students' views of the PBL environment can be detected.

Table 10

Rotated component matrix PBLEI

	Components				
Item no	TS	SR	SIC	QP	α
1	.803				
2	.661				
3	.733				
4	.751				0.90
5	.722				
6	.804				
7	.678				
8		.561			
9		.594			0.75
10		.668			
11		.665			
12			.883		
13			.869		
14			.580		
15			.781		0.81
16			.657		
17			.663		
18				.568	
19				.853	0.74
20				.558	
21				.788	
α-Instrument		0.91			

PBL and Students' SEBs

Table 11 shows the ANOVA results of the CAEQ SEBs variables. ACT scores, GPA, and student major did not influence SEBs in both semesters. Generally, the number of chemistry courses influenced students' SEBs scores. Post-Hoc Tukey's test showed that sttudents with four or more chemistry courses had significantly higher SEBs scores.

The instructor also influenced SEBs results in both CHEM 1 pre- and post-test and CHEM 2 pre-test.

Table 11

ANOVA of self-efficacy results

	CHEM 1 F			CHEM 2 F		
Variable	N	Pre	Post	N	Pre	Post
ACT	84	1.36	0.75	82	0.91	2.24
Courses	81	3.62*	4.72*	87	2.78*	1.65
Major	84	1.72	1.63	75	0.92	1.53
Instructor	85	2.90*	3.20*	93	8.27**	1.77
GPA	85	0.52	0.67	87	1.16	1.36

Post-hoc analysis indicated no difference in mean scores amongst students taught by different instructors in CHEM 1 pre-test, but a difference in individual SEBs means for instructors in both CHEM 1 post-test and CHEM 2 pre-test. The post-hoc analysis in CHEM 1 indicated that mean SEBs scores from Jeff's class were significantly lower than that from John's classes for the post-test only. In CHEM 2 pre-test scores, Jeff had significantly lower scores than Norma, however, Jeff's students had the highest improvement in SEBs scores to catch up with students from the other instructors. It is possible that after using PBL instruction for two semesters, Jeff become more confident in using the method than before.

PBL and SEBs: CHEM 1

Gender

The influence of gender on students' self-efficacy beliefs scores in CHEM 1 was investigated using an independent t-test (Table 12). First, Kolmogorov-Sminorf tests were conducted to determine the type of distribution of data. All the p-values obtained were greater than 0.05, and hence, the gender SEBs scores were also normally distributed.

The F-test from the Levene's test on the influence of gender were greater than 0.05 indicating that there was equal variance between SEBs score of male and female participants. In this case, the t-value was 3.038 ($p = 0.003$) indicating that gender influenced the pre-SEBs scores in CHEM 1. However, this influence did not persist in the post-test ($t = 1.922$, $p = 0.058$). Possibly, instruction through PBL closed the observed gender gap between male and female participants' SEBs scores.

Table 12

Independent t-test for gender influence on CHEM 1 SEBs

	Male (N = 56)	Female (N = 29)	t	p
Pre-test	4.86	4.18	3.038	0.003
Post-test	5.13	4.76	1.922	0.058

Item by item analysis was conducted to determine how gender affected SEBs between pre- and post-tests (Table 13). A difference was observed on the pre-test results for 6 items (1, 2, 4, 5, 7, 10). Item 1 asks participants to rate their self-efficacy for *Reading the procedures for an experiment and conducting the experiment without supervision*. The difference for this item was persistent but slightly reduced during the post-test. Item 2 deals with *Ensuring that data obtained from an experiment is accurate*. The difference for this item was not persistent to the post-test. This shows that the female students improved their SEBs on this item, completing the unit with scores comparable to the male participants' scores. Item 4 deals with *Explaining something that you learned in* *this chemistry course to another person.* The difference for this item did not persist to the post-test indicating that the female participants improved their confidence more than the male participants. Item 5 is about *Converting the data obtained in a chemistry experiment into results.* Similarly, the difference did not persist into the post-tests. The female participants had the highest improvement on this item (Δm = 1.50) practically offsetting the male participants' score. Item 7 deals with *Designing and conducting a chemistry experiment*. For this item, the difference between male and female participants persisted, but female students still had a higher increase in SEBS (Δm = 0.30) than their male counterparts (Δm = 0.05). Similarly, the difference persisted for item 10, *Applying theory learned in a lecture for a laboratory experiment*.

Table 13

Item analysis for gender-SEBs CHEM 1

Item	Pretest			Posttest		
	Male	Fem	Δm	Male	Fem	Δm
1	3.65	2.10	1.55**	4.00	2.67	1.33**
2	4.91	3.90	1.01**	4.98	4.40	0.58*
3	4.47	4.03	0.44	5.40	5.07	0.33
4	5.00	3.93	1.07**	5.13	4.57	0.56
5	4.93	3.83	1.10**	5.31	5.33	-0.02
6	5.55	5.30	0.25	5.45	5.70	-0.25
7	4.84	3.93	0.91**	4.89	4.23	0.66*
8	5.25	5.20	0.05	5.45	5.53	-0.08
9	5.15	5.27	-0.12	5.47	5.33	0.14
10	4.76	3.97	0.79*	5.00	4.17	0.83**
11	5.05	4.63	0.42	5.42	5.40	0.02

**Significant at p <0.01
*Significant at p<0.01

PBL and Changes in Chemistry SEBs

Frequency of scores. Figure 2 shows the distribution of score intervals between pre- and post-test self-efficacy beliefs scores. This presents a crude picture of how the distribution of students' self-efficacy scores changed before and after PBL instruction. Before the PBL instruction, 54 students out of 85 had self-efficacy beliefs scores of 4 or less out of 7, representing 64% of the total population. However, this number decreased at the post test to only 35, representing 41%. This implies that the percentage of students having self-efficacy beliefs scores greater than 4 increased from 36% to 67% during the post-test. A cursory look at these percentages show that PBL increased the number of students with higher self-efficacy scores.

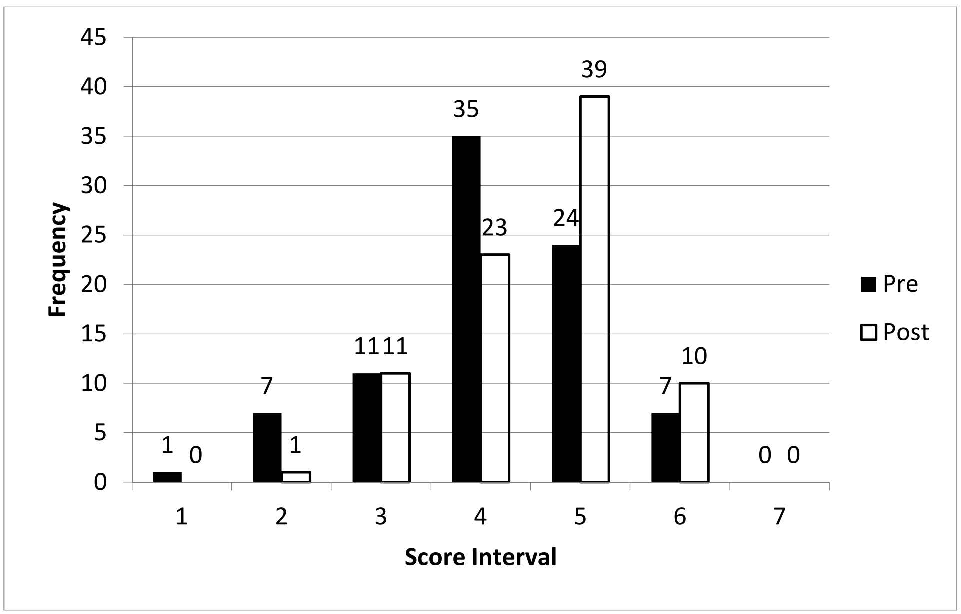

Figure 2. Frequency scores for SEBs CHEM 1

Test of normality of data. In line with fulfilling the requirements of parametric tests, Kolmogorov-Sminorv tests were carried out using SPSS to determine whether or not the pre- and post-test self-efficacy beliefs scores were uniformly distributed for parametric data analysis. The Z-score was 0.82 (not shown) and the p-value was 0.740, showing that the SEBs scores were uniformly distributed. This indicates that parametric analysis can be used to interpret the data.

Descriptive statistics. Table 14 shows descriptive statistics for pre- and post-test self-efficacy beliefs scores. The mean scores are 4.67 and 5.04 for pre- and post-tests, respectively. The median for pre- and post-tests are 4.82 and 5.18, respectively. The minimum and maximum scores from the pre-test are 2.45 and 6.45 (range = 4.00) respectively. The minimum and maximum scores from the post-test are 2.82 and 6.64 (range = 3.82) respectively. The data show that the minima and maxima for post-test are higher than those for the pre-test scores. The highest score for each quartile is also presented in the table. Similarly, the data show that in each quartile, the post-test scores are higher than the pre-test scores. All the measures of central tendency, mean, median, and mode indicate that the students had medium to higher SEBs in chemistry.

Table 14

Descriptive statistics for CHEM 1 SEBs

		Pre-SEBs	Post-SEBs
N	Valid	85	85
	Missing	83	83
Mean		4.63	5.01
Median		4.82	5.18
Mode		4.91	4.55[a]
Std. Deviation		1.03	0.88
Minimum		1.73	2.82
Maximum		6.73	6.64
Percentiles	25	4.14	4.50
	50	4.82	5.18
	75	5.27	5.64

a. Multiple modes exist. The smallest value is shown

Inferential statistics. Two assumptions must be fulfilled to conduct a paired sample t-test.

1. The dependent variable (difference scores) is normally distributed in the two conditions.

2. The independent variable is dichotomous and its levels (groups or occasions) are paired, or matched, in some way (e.g., pre-post, concern for pay-concern for security, etc.).

In this case, assumption 1 has been fulfilled by the results of the Kolmogorov-Sminorv tests. The second assumption has been fulfilled because we have two levels that are paired for each individual (pre- vs post-test score).

To determine the relationship between PBL and self-efficacy beliefs, paired sample t-test was carried out. Table 15 shows descriptive statistics that compare chemistry students' self-efficacy scores before and after PBL. The mean self-efficacy score improved from 4.63 to 5.01 between pre- and post-tests respectively. The trend indicates that the two mean scores are different. This difference may be due to chance, hence inferential statistics are used to test whether or not the difference is significant. The t-value of this difference is 4.97 and the probability level of this difference is 0.000 (or <0.001). With an α level of 0.05, this difference is statistically significant.

To test how meaningful this difference is in education, we calculated Cohen's d from absolute value of Δm and the standard deviation of the difference using the formula

$$d = \frac{\Delta m}{SD}$$

where *Δm* is the change is the difference in mean score between the pre- and pos-test and SD is the pooled standard deviation. The effect size provides information about how many standard deviations difference there is between the pre- and post-test. In simple terms, it asks the question, “Is the difference big enough to be considered useful for a specific purpose?” In this case $\Delta m = 0.375$ and SDpooled = 0.697. According to Cohen,s rule of thumb, 0.20, 0.50, and 0.80 are small, medium, and large effect sizes respectively. Using the formula above, Cohen’s d was found to be 0.54. This result shows a medium practical significance. This observation indicates that the improvement in scores was not only statistically significant, but also practically significant. Further analysis of the data using paired sample t-test showed that students who had SEBs scores of less than 5 had a significant improvement ($p < 0.05$) in SEBs. However, students with SEBs scores of 5 and above did not show a significant improvement.

Individual item analyses were conducted to determine how student SEBs changed with PBL. Table 16 shows results of individual item analysis. The trend indicates an improvement on all the items between pre-and post-tests.

Table 15

Paired sample t-test of CHEM 1 SEBs data

Test	N = 85	Test score	t	p	Δm	SDpooled	d
Pre-test		4.63	4.97	0.000	0.375	0.697	0.54
Post-test		5.01					

The highest change was observed on item 3 ($\Delta m = 0.96$), *Proposing a meaningful question that could be answered experimentally,* followed by item 5 ($\Delta m = 0.78$), *Convert the data obtained in a chemistry experiment into results.* Items with the lowest change were 6 ($\Delta m = 0.08$), *After reading an article about a chemistry experiment, writing a summary of the main points* and 7 ($\Delta m = 0.14$), *Designing and conducting a* *chemistry experiment.* Results from statistical analysis show a significant improvement on four items ($p < 0.05$; items 1, 3, 5 and 11).

Table 16

Individual item analysis for CHEM 1 SEBs

CHEM 1	Pre	Post
1. Reading the procedures for an experiment and conducting the experiment without supervision	3.11	3.53**
2. Ensuring that data obtained from an experiment is accurate	4.55	4.78
3. Proposing a meaningful question that could be answered experimentally	4.32	5.28**
4. Explaining something that you learned in this chemistry course to another person	4.62	4.93
5. Convert the data obtained in a chemistry experiment into results	4.54	5.32**
6. After reading an article about a chemistry experiment, writing a summary of the main points	5.46	5.54
7. Designing and conducting a chemistry experiment	4.52	4.66
8. Writing up the experimental procedures in a laboratory report	5.24	5.48
9. After watching a television documentary dealing with some aspect of chemistry, writing a summary of its main points	5.19	5.42
10. Applying theory learned in a lecture for a laboratory experiment	4.48	4.71
11. Writing up the results section in a laboratory report	4.91	5.41**

**Significant at $p < 0.001$

PBL and SEBS: CHEM 2

Influence of Gender

The influence of gender on students' SEBs scores in the CHEM 2 was also investigated using independent t-test. Kolmogorov-Sminorv tests also indicated that the data for both gender groups was normally distributed. Levene's F-test results indicated differences in variance between male and female participants during the pre-test (F =

6.503, p = 0.012), but no difference in variance was observed in the post-test (F = 3.37, p = 0.070). Therefore, the t-value for unequal variance was used in the pre-test analysis.

Table 17 shows that female participants had a higher mean SEBs score (m = 5.09) than their male counterparts (m = 5.00). Similar results were observed in the post-test SEBs scores with male participants obtaining 5.33 while their female counterparts had 5.36. The t-values of pre- and post-tests are 0.49 (p = 0.657) and 1.62 (p = 0.972), respectively. These t-values show that there was no statistical difference on SEBs scores between male and female participants in CHEM 2.

Table 17

Independent t-test for gender influence on CHEM 2 SEBs

	Male (N = 56)	Female (N = 29)	t	p
Pre-test	5.00	5.09	0.49	0.657
Post-test	5.33	5.36	1.62	0.872

Item by item analysis (Table 18) indicated no difference between male and female participants except for item number 11 which shows female students having more confidence in writing up the results section in a laboratory report; however, the difference did not persist to the post-test.

PBL and Changes in Chemistry SEBs

Frequency of scores. Figure 3 shows the distribution of score intervals between pre- and post-test self-efficacy beliefs scores. This presents a crude picture of how the distribution of students' self-efficacy scores changed before and after PBL instruction. Before the PBL instruction, 37 students out of 93 had self-efficacy beliefs scores of 4 or less representing 40% of the total population. However, this number decreased at the post test to only 24 representing 26%.

Table 18

Item analysis for gender-SEBs CHEM 2

	Pre-test			Post-test		
Item no.	Male	Female	Δm	Male	Female	Δm
1	5.02	4.70	0.32	5.26	5.20	0.06
2	4.74	4.48	0.26	5.06	4.73	0.33
3	4.68	4.95	-0.27	5.36	5.33	0.03
4	5.08	5.15	-0.07	5.09	5.48	-0.38
5	5.02	5.10	-0.08	5.34	5.43	-0.09
6	5.30	5.65	-0.35	5.57	5.90	-0.33
7	4.02	4.38	-0.36	4.68	4.65	0.03
8	5.47	5.85	-0.38	5.55	5.98	-0.43
9	5.40	5.85	-0.45	5.60	5.95	-0.35
10	4.74	4.55	0.19	5.11	4.83	0.29
11	5.15	5.70	-0.55*	5.74	5.90	-0.16

This implies that the percentage of students having self-efficacy beliefs scores greater than 4 increased from 60% to 74%. A cursory look at these percentages shows that instruction through PBL has increased the number of students with higher self-efficacy scores.

Descriptive statistics. Table 19 shows descriptive statistics for the pre- and post-test of the SEBs scores. The mean scores are 5.03 and 5.34 for pre- and post-tests, respectively. The median for pre- and post-tests are 5.18 and 5.45, respectively. The minimum and maximum scores for the pre-test are 1.45 and 6.64 (range = 5.18),

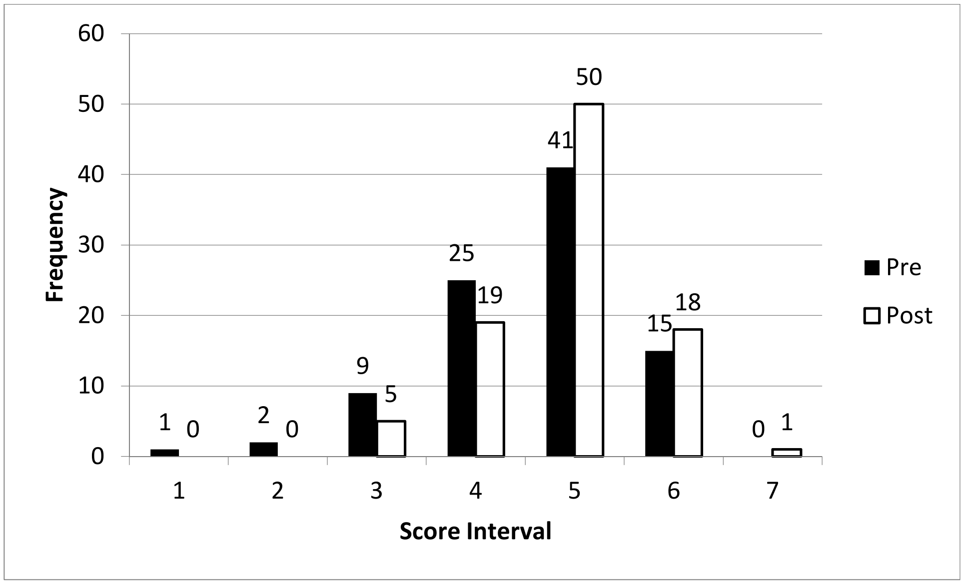

Figure 3. Frequency scores for SEBs CHEM 2

respectively, and those for the the post-test are 3.00 and 7.00 (range = 4.00), respectively. The data also shows that the minima and maxima for post-test scores are higher than those for the pre-test scores. The highest score for each quartile is also presented in the table. Similarly, the data shows that in each quartile, the pre-test scores are higher than the post-test scores.

Inferential statistics. The calculated Z-value ($Z = 1.14$) and the p-value ($p = 0.147$) for the SEBs scores indicated that the data was normally distributed. To determine the relationship between PBL and SEBs, a paired sample t-test was also carried out.

Table 20 shows descriptive statistics that compare chemistry students' SEBs scores before and after PBL. The mean SEBs score improved from 5.03 to 5.34 between pre- and post-tests respectively. The trend also indicates that the two means are different. The t-value of the difference between pre- and post-tests SEBs scores is 4.699, and the probability level of this difference is 0.000.

Table 19

Descriptive statistics for CHEM 2 SEBs

Statistic		Pre-test	Post-test
N		93	93
Mean		5.03	5.34
Median		5.18	5.45
Mode		5.36	5.73
Std. Deviation		0.94	0.82
Range		5.18	4.00
Minimum		1.45	3.00
Maximum		6.64	7.00
Percentiles	25	4.45	4.86
	50	5.18	5.45
	75	5.68	5.91

As our α level is 0.05, this difference is statistically significant. To test the practicality of this data, Cohen's d was calculated using equation (1) and was found to be 0.49. This observation indicates that the relationship was not only statistically significant, but also practically significant. Further analysis of the data using paired sample t-test showed that students who had SEBs scores of less than 5 had a significant improvement ($p < 0.05$) in SEBs. However, students with SEBs scores of 5 and above did not show a significant improvement.

The individual item analyses were conducted to determine how students' SEBs changed with PBL. Table 21 shows results of individual item analysis. The trend indicates an improvement on all the items between pre-and post-tests.

The highest change was observed on item 3 (Δm = 0.54), *Proposing a meaningful question that could be answered experimentally,* followed by item 5 (Δm = 0.50),

Table 20

Paired sample t-test of CHEM 2 SEBs data

Test	N = 93	Test score	t	p	Δm	SDpooled	d
Pre-test		5.03	4.70	0.000	0.312	0.640	0.49
Post-test		5.34					

Table 21

Individual item analysis for CHEM 2 SEBs

No	CHEM 2	Pre	Post
1	Reading the procedures for an experiment and conducting the experiment without supervision	4.88	5.24**
2	Ensuring that data obtained from an experiment is accurate	4.62	4.91*
3	Proposing a meaningful question that could be answered experimentally	4.80	5.34**
4	Explaining something that you learned in this chemistry course to another person	5.12	5.26
5	Convert the data obtained in a chemistry experiment into results	5.05	5.38**
6	After reading an article about a chemistry experiment, writing a summary of the main points	5.45	5.71*
7	Designing and conducting a chemistry experiment	4.17	4.67**
8	Writing up the experimental procedures in a laboratory report	5.63	5.73
9	After watching a television documentary dealing with some aspect of chemistry, writing a summary of its main points	5.59	5.75
10	Applying theory learned in a lecture for a laboratory experiment	4.66	4.99*
11	Writing up the results section in a laboratory report	5.39	5.81**

*Significant at $p < 0.05$
**Significant at $p < 0.01$

Designing and conducting a chemistry experiment. Items with the lowest change were 8 (Δm = 0.10), *Writing up the experimental procedures in a laboratory report* and 4 (Δm = 0.14), *Explaining something that you learned in this chemistry course to another person.*

Results from Wilcox signed rank for two related samples statistical analysis show a significant improvement on eight items. Only three items (4, 8, and 9) showed no significant change between pre- and post-tests.

PBL and Students' Attitudes

Table 22 shows the ANOVA results of the attitudes variables. ACT scores, GPA, student major, and instructors did not influence attitude scores in both semesters. The influence of the number of chemistry courses taken was observed for both pre- ($F = 3.31$, $p = 0.042$) and post-test ($F = 7.42$, $p = 0.001$) in CHEM 1 and the pretest in CHEM 2 ($F = 3.01$, $p = 0.035$) semesters. Post-hoc analysis for CHEM 1 post-test results indicates that students with four or more courses had a significantly higher attitude scores than students with 2 or less chemistry courses.

Table 22

ANOVA of attitudes results

	CHEM 1 F			CHEM 2 F		
Variable	N	Pre	Post	N	Pre	Post
ACT	84	0.72	0.85	82	1.55	0.67
Courses	81	3.31*	7.42**	87	3.01*	1.49
Major	84	1.61	1.82	75	1.57	1.18
Instructor	85	0.05	0.75	93	0.34	0.16
GPA	85	0.87	0.65	87	1.59	1.54

*Significant at p = 0.05
**Significant at p = 0.01

For CHEM 2 results, the post-hoc analysis indicated that the difference in the pre-test attitudes scores was due to means for students with two or less courses and those with five or more courses.

Influence of Gender on Attitudes

To determine the influence of gender on attitudes, an independent t-test was also conducted. Before conducting the t-test, a Kolmogorov-Sminorv test was also conducted to determine the distribution of the attitudes scores, and the KS Z ranged from 0.434 to 0.757 with a probability range of 0.615 to 0.992. This indicates that the distribution of male and female participants' attitudes scores was also normal, hence parametric tests were used to analyze the data. The descriptive data shows very little difference of attitude scores between male and female participants. This assertion is confirmed by inferential statistics (Table 23), which indicates probablility values above the alpha level of 0.05. This indicates that male and female participants had similar attitudes before and after the PBL instruction.

Table 23

Independent t-test for gender influence on CHEM 1 attitudes

	Male (N = 56)	Female (N = 29)	t	p
Pre-test	4.86	5.05	1.25	0.215
Post-test	4.98	5.08	0.53	0.569

Item by item analysis (Table 24) showed a difference in the pre-test attitude scores between male and female participants on item 7, *chemists are indifferent or inquisitive*, Item 13, *science documentaries are boring or enjoyable* and item 14, *science websites are boring or enjoyable*. The mean scores indicate that female participants felt that chemists are more inquisitive than their male counterparts. Male participants had a more positive attitude on items 13 and 14. These differences did not persist to the post-test. For the post-test, female participants outscored their male counterparts on item number 2 , *chemists are socially unaware or aware* and item number 15, *chemistry websites are boring or interesting.*

PBL and Changes in Chemistry Attitudes

Frequency of scores. Figure 4 shows the distribution of score intervals between pre- and post-test attitudes scores. This presents a crude picture of how the distribution of students' attitudes scores changed before and after PBL instruction. Before the PBL instruction, 43 students out of 85 had attitudes scores of 4 or less and this number decreased slightly to 40 during the post-test. It was also observed that more students had an attitude score of 6 during the post-test than the pre-test.

Descriptive statistics. Table 25 shows descriptive statistics for pre- and post-tests of the attitudes scores. The mean scores are 5.03 and 5.34 for pre- and post-tests respectively. The median for pre- and post-tests are 5.18 and 5.45 respectively. The minimum and maximum scores for the pre-test are 1.45 and 6.64 (range = 5.18) respectively. The minimum and maximum scores of the post-test are 3.00 and 7.00 (range = 4.00) respectively. The data show that the minima and maxima for post-test are higher than those for the pre-test scores.

The highest score for each quartile is also presented in the table. The data shows that in the two higher quartiles, the pre-test scores are higher than the post-test scores. All the measures of central tendency, mean, median, and mode indicate that most students had neutral to positive attitudes toward chemistry.

Table 24

Item analysis for gender-Attitudes CHEM 1

	Pre-test			Post-test		
Item no.	Male	Female	Δm	Male	Female	Δm
1	3.60	3.87	-0.27	3.60	4.00	-0.40
2	4.29	4.70	-0.41	4.29	5.13	-0.84*
3	5.51	5.80	-0.29	5.51	5.83	-0.32
4	4.11	4.37	-0.26	4.11	4.40	-0.29
5	4.67	4.73	-0.06	4.67	5.07	-0.40
6	4.62	4.93	-0.31	4.62	5.00	-0.38
7	5.13	5.83	-0.70	5.13	5.70	-0.57
8	5.05	5.23	-0.18	5.05	5.43	-0.38
9	5.76	5.90	-0.14	5.76	5.60	0.16
10	5.89	5.93	-0.04	5.89	5.53	0.36
11	5.64	5.63	0.01	5.64	5.50	0.14
12	6.02	5.67	0.35	6.02	5.70	0.32
13	4.47	3.23	1.24	4.47	3.47	1.00
14	3.35	2.63	0.72	3.35	3.13	0.22
15	5.76	6.07	-0.31	5.76	6.07	-0.31*
16	4.44	4.50	-0.06	4.44	4.63	-0.19
17	4.62	4.03	0.59	4.62	4.20	0.42
18	4.55	4.50	0.05	4.55	4.73	-0.18
19	3.84	3.70	0.14	3.84	3.77	0.07

*Significant at $p < 0.05$

Inferential statistics. The calculated Z-value ($Z = 0.91$) and the p-value ($p = 0.376$) for the attitudes scores indicated that the data was normally distributed. To determine the relationship between PBL and attitudes scores, paired sample t-test was also carried out. Table 26 shows descriptive statistics that compare chemistry students' attitudes scores before and after PBL. The mean attitudes score between pre-and post-tests improved from 4.93 to 5.01 respectively. The trend also indicates that the two means are different. The t-value of this difference is 1.24, and the probability level of this difference is 0.220. This implies that there is no significant difference between the pre- and post-test attitudes scores.

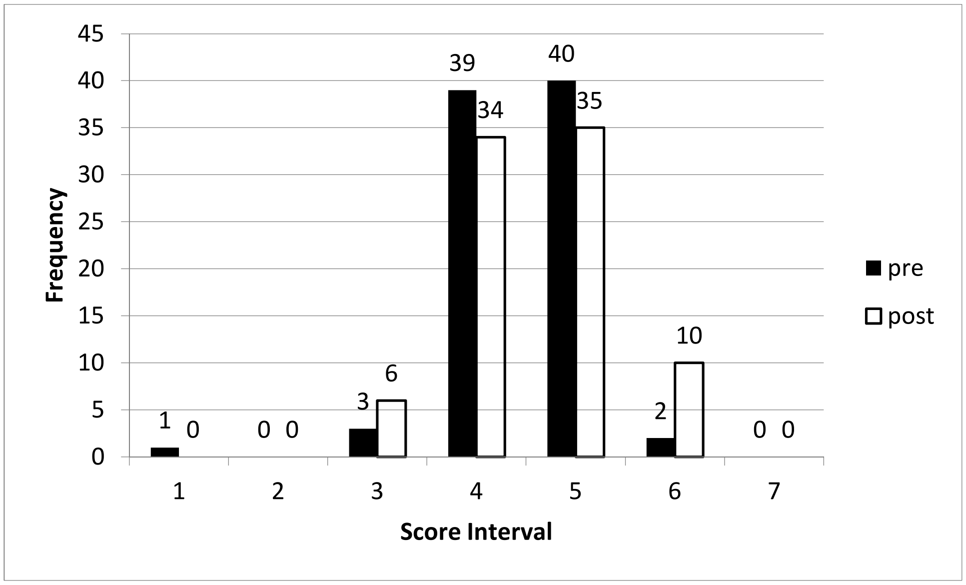

Figure 4. Frequency scores for attitudes in CHEM 1

Table 25

Descriptive statistics for CHEM 1 attitudes

		Pre-test	Post-test
N		85	85
Mean		4.93	5.02
Median		4.94	5.00
Mode		4.53	5.06
Std. Deviation		0.74	0.76
Range		5.21	3.36
Minimum		1.00	3.35
Maximum		6.21	6.71
Percentiles	25	4.53	4.53
	50	4.94	5.00
	75	5.41	5.56

However, Further analysis of the data using paired sample t-test showed that students who had SEBs scores of less than 4.5 had a significant improvement ($p = 0.04$)

in SEBs. However, students with attitudes scores of 4.5 and above did not show a significant improvement.

Table 26

Paired sample t-test of CHEM 1 attitudes data

Test N = 93	Test score	t	p	Δm	SDpooled	d
Pre-test	4.93	1.24	0.220	0.087	0.647	-
Post-test	5.02					

As with SEBs, individual item analyses were also conducted to determine how student attitudes changed with PBL. Table 27 shows results of individual item analysis. The trend indicates an improvement on ten items and a decrease on nine items between pre- and post-test. The highest change was observed on item 4 (Δm = 0.41), *chemists have fixed or flexible ideas*, followed by item 2 (Δm = 0.35), *chemists are socially aware or unaware*. The highest attitude decrease was observed on item 10 (-0.16), *chemistry research decreases or improves quality of life*, followed by item 17 (Δm = -0.14), *chemistry research is boring or interesting*. Results from statistical analysis show a significant improvement on four items (items 1, 2, 4, and 14).

PBL and Attitudes in CHEM 2

Influence of Gender on Attitudes

To determine the influence of gender on attitudes an independent t-test was also conducted. Before conducting the t-test, a Kolmogorov-Sminorv test was also conducted to determine the distribution of the attitudes scores, and the KS Z ranged from 0.756 to

0.836 with a probability range of 0.487 to 0.617.

Table 27

Individual item analysis for CHEM 1 attitudes

Item	Item descriptor		Pre	Post
		Chemists are		
1	Unfit	Athletic	3.69	3.92*
2	Socially unaware	Socially aware	4.43	4.78**
3	Environmentally unaware	Environmentally aware	5.62	5.82
4	Fixed in their ideas	Flexible in their ideas	4.20	4.61*
5	Only care about their results	Care about the effects of their results	4.69	4.79
6	Unimaginative	Imaginative	4.73	4.93
7	Indifferent	Inquisitive	5.38	5.41
8	Impatient	Patience	5.12	5.28
		Chemistry research		
9	Harms people	Helps people	5.81	5.69
10	Decreases quality of life	Improves quality of life	5.91	5.75
11	Creates problems	Solves problems	5.64	5.61
12	Causes society to decline	Advances society	5.89	5.84
		Science documentaries		
13	Boring	Interesting	4.04	3.98
		Chemistry websites		
14	Boring	Interesting	3.09	3.39
		Chemistry jobs		
15	Unchallenging	Challenging	5.87	5.74
16	Repetitive	Varied	4.46	4.59
17	Boring	Interesting	4.41	4.27
18	Unsatisfying	Satisfying	4.53	4.58
19	Tedious	Exciting	3.79	3.96

*Significant at $p < 0.05$

This indicates that the distribution of male and female participants was normal, hence parametric tests were used to analyze the data.

The descriptive data shows very little difference of attitude scores between male and female participants. This assertion is confirmed by inferential statistics (Table 28), which indicates probablility values above the alpha level of 0.05. This indicates that male and female participants had similar attitudes before and after the PBL instruction.

Table 28

Independent t-test for gender influence on CHEM 2 attitudes

	Male (N = 56)	Female (N = 37)	t	p
Pre-test	5.16	5.21	0.38	0.706
Post-test	5.23	5.27	0.29	0.774

For item and item analysis (Table 29), the difference was observed only for item 1, *"Chemists are unfit or fit"*. However, the data show that female participants generally had higher attitudes on both pre- and post-tests.

PBL and Changes in Chemistry Attitudes

Frequency of scores. Figure 5 shows the distribution of score intervals between pre- and post-test attitudes scores. Before the PBL instruction 32 students out of 93 had attitudes scores of less than 5 and this number did not change much in the post test. It was also observed that more students had an attitude score of 6 during the post-test than the pre-test. Further, Figure 5 shows that students already had positive attitudes toward chemistry since most scores were above 5.

Descriptive statistics. Table 30 shows descriptive statistics for pre- and post-tests of the attitudes scores. The mean scores are 5.17 and 5.24 for pre- and post-tests, respectively. The median for pre- and post-tests are 5.26 and 5.32, respectively. The minimum and maximum scores for the pre-test are 2.84 and 6.68 (range = 3.84), respectively.

Table 29

Item analysis for gender-Attitudes CHEM 2

	Pre-test			Post-test		
Item no.	Male	Female	Δm	Male	Female	Δm
1	3.83	4.43	-0.60*	3.82	4.36	-0.53
2	4.67	5.11	-0.44	4.71	5.25	-0.54
3	5.83	5.57	0.26	5.67	5.86	-0.19
4	4.88	4.43	0.45	5.00	4.93	0.07
5	5.02	5.11	-0.09	5.27	5.25	0.02
6	4.96	5.11	-0.15	5.09	5.36	-0.27
7	5.38	5.93	-0.55	5.47	5.79	-0.32
8	5.15	5.29	-0.14	5.09	5.46	-0.38
9	6.00	6.18	-0.18	5.89	5.93	-0.04
10	5.98	6.04	-0.06	6.00	6.00	0.00
11	5.83	6.00	-0.17	5.80	5.86	-0.06
12	6.04	6.29	-0.24	6.00	6.18	-0.18
13	4.94	4.57	0.37	4.76	4.54	0.22
14	4.13	3.71	0.41	3.87	4.04	-0.17
15	5.83	6.04	-0.20	5.73	6.00	-0.27
161	4.46	4.93	-0.47	4.73	5.14	-0.41
71	4.90	5.07	-0.18	4.98	5.11	-0.13
81	4.90	5.14	-0.25	5.09	5.14	-0.05
19	4.06	4.14	-0.08	4.56	4.64	-0.09

*Significant at $p < 0.05$

The minimum and maximum scores of the post-test are 3.63 and 6.68 (range = 3.05), respectively. The highest scores for each quartile are also presented in the table. Similarly, the data shows that in each quartile, the pre-test scores are higher than the post-test scores. All the measures of central tendency, mean, median, and mode indicate that most students had higher attitudes toward chemistry following PBL instruction.

Inferential statistics. The calculated Z-value ($Z = 0.91$) and the p-value ($p = 0.376$) for the attitudes scores indicated that the data was normally distributed.

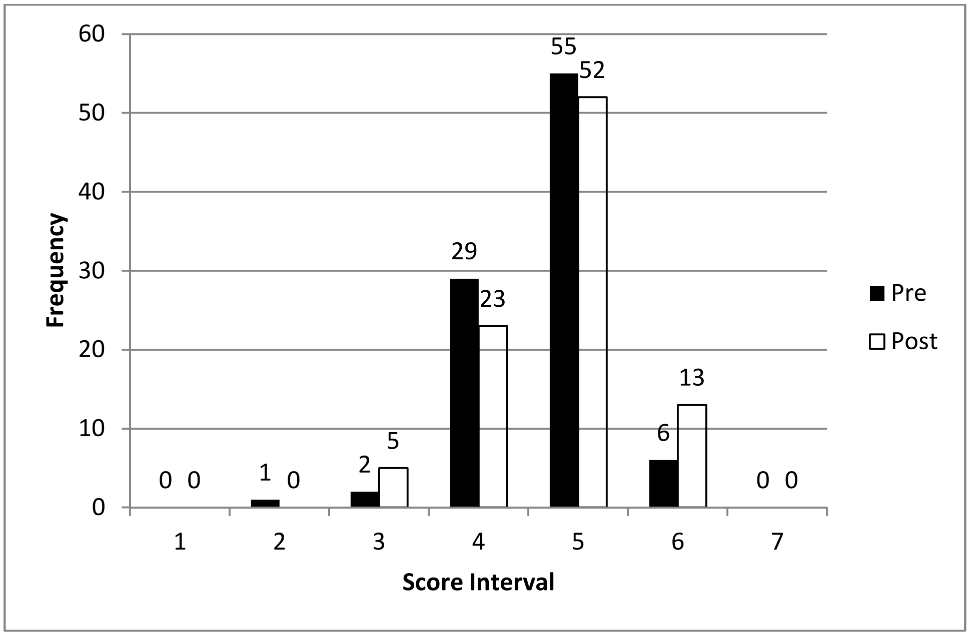

Figure 5. Frequency scores for attitudes in CHEM 2

Table 30

Descriptive statistics for CHEM 2 attitudes

Statistic		Pre-test	Post-test
N		93	93
Mean		5.18	5.25
Median		5.26	5.32
Mode		5.11	5.47
Std. Deviation		0.66	0.67
Range		3.84	3.05
Minimum		2.84	3.63
Maximum		6.68	6.68
Percentiles	25	4.68	4.79
	50	5.26	5.32
	75	5.63	5.68

To determine the relationship between PBL and attitudes scores, a paired sample t-test was also carried out. Table 31 shows descriptive statistics that compare chemistry students' attitudes scores before and after PBL. The mean attitudes scores between pre- and post-tests improved slightly from 5.18 to 5.25, respectively. The t-value of this difference is 1.36, and the probability level of this difference is 0.175. This implies that there is no significant difference between the pre- and post-test attitudes scores. Further analysis of the data using paired sample t-test showed that students who had SEBs scores of less than 5 had a significant improvement ($p = 0.02$) in attitudes toward chemistry. However, students with SEBs scores of 5 and above did not show a significant improvement.

Table 31

Paired sample t-test of CHEM 2 attitudes data

Test	N = 93	Test score	t	p	Δm	SDpooled	d
Pre-test		5.18	1.36	0.175	0.068	0.480	-
Post-test		5.25					

As with SEBs, individual item analyses were also conducted to determine how student attitudes changed with PBL. Table 32 shows results of individual item analysis. The trend indicates an improvement on eleven items and a decrease on eight items between pre- and post-test. The highest change was observed on item 19 (Δm = 0.38), *chemists are tedious or exciting followed by item 4, chemists have fixed or flexible ideas* (Δm = 0.31). The highest attitude decrease was observed on items 9 and 11 (-0.14), *chemistry harms/helps people and creates/solves problem*, followed by item 15 (Δm = -0.13), *chemistry is unchallenging/challenging*. Results from statistical analysis show a significant improvement on two items (items 4 and 19).

Table 32

Individual item analysis for attitudes in CHEM 2

Item	Item descriptor		Pre	Post
		Chemists are		
1	Unfit	athletic	4.08	4.06
2	socially unaware	socially aware	4.84	5.04
3	environmentally unaware	environmentally aware	5.80	5.81
4	fixed in their ideas	flexible in their ideas	4.70	5.01*
5	only care about their results	care about the effects of their results	5.06	5.31
6	unimaginative	imaginative	5.06	5.29
7	indifferent	inquisitive	5.63	5.71
8	impatient	patience	5.33	5.41
		Chemistry research		
9	harms people	helps people	6.09	5.95
10	decreases quality of life	improves quality of life	6.00	5.96
11	creates problems	solves problems	5.95	5.81
12	causes society to decline	advances society	6.13	6.10
		Science documentaries		
13	Boring	Interesting	4.85	4.75
		Chemistry websites		
14	Boring	Interesting	4.05	3.98
		Chemistry jobs		
15	unchallenging	challenging	5.96	5.83
16	repetitive	varied	4.62	4.89
17	boring	interesting	5.01	5.08
18	unsatisfying	satisfying	5.03	5.16
19	tedious	exciting	4.17	4.55*

*Significant at $p < 0.05$

Students' Views of the PBL Environment

Figure 6 shows a pie chart containing percentage scores for various score ranges on the PBLEI. Only 3.6% of the students had scores of less than 3 and a total of 29 % of students had a score of less than 4. A high percentage of students (71%) had scores of 4 or greater. The scores imply that most students had better attitudes toward the PBL environment as expected for students centered learning techniques (Dochy et al., 2005).

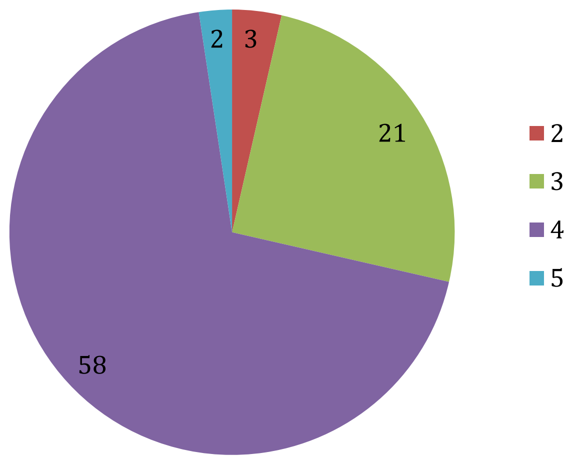

Figure 6. Distribution of PBLEI scores in CHEM 1

Scores for individual sections of the PBLEI are shown in Figure 7. The sections comprise teacher support (TS), student responsibility (SR), student interactions and collaboration (SIC), and quality of a problem (QP). Clearly, students felt that students' interaction and collaboration (SIC) was the highest in these classes, seconded by student responsibility. The lowest score was given to quality of the problem (QP), seconded by teacher support (TS). However, it is important to note that the mean scores for each section are much higher than 3, indicating that students had attitudes consistent with what we would expect for PBL (Dochy et al., 2005). It is also interesting to note that students had higher view of themselves performing within the PBL environment compared to the assistance provided by the instructor.

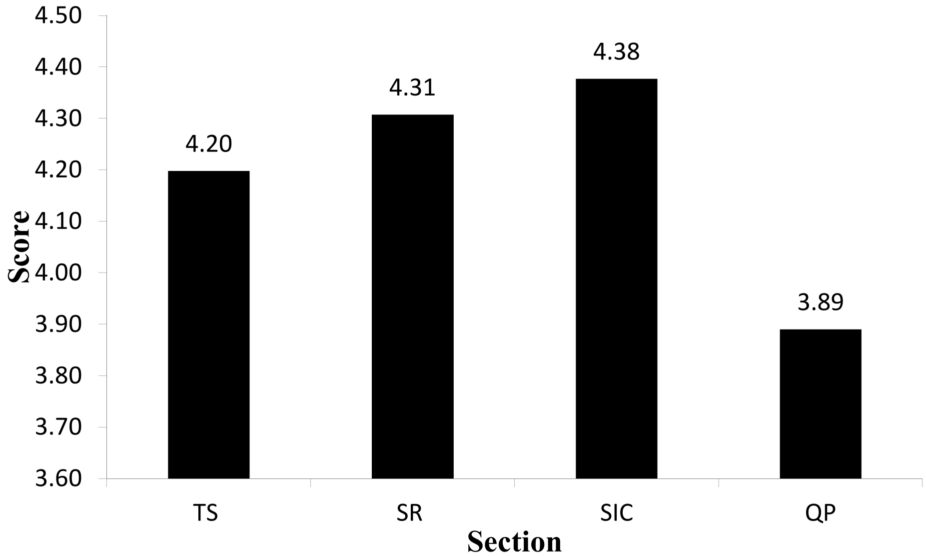

Figure 7. PBLEI scores per each section in CHEM 1

ANOVA was carried out to determine whether or not the differences shown in Figure 7 were meaningful (Table 33). The F- and the p-values (F-10.536, p = 0.000) indicate that the difference is not just due to chance, but the variations amongst the instrument sections. Post-hoc analysis indicates that QP was significantly lower than the rest of the other sections. This indicates that students' view of the quality of the PBL problem was statistically lower than the rest of the sections.

Table 33

ANOVA for CHEM 1 PBLEI

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	12.638	3	4.213	10.84	.000
Within Groups	139.964	360	.389		
Total	152.602	363			

Correlation analyses were carried out to determine the relationships amongst scores from various sections of the PBLEI survey (Table 34). All the sections were highly correlated, however, the highest correlations were observed between SR and TS (r = 0.636) and SR and SIC (r = 0.671). This implied that, students who felt that student responsibility (SR) was adequate also felt that teacher support (TS) and student interaction and collaboration (SIC) were also highly adequate and vice versa. The whole table indicates that all the sections must be carefully planned because of these significant multiple correlations.

Table 34

Pearson correlation parameters for CHEM 1 PBLEI sections

		TS	SR	SIC	QP
TS	r	1	.636**	.470**	.422**
	p		.000	.000	.000
SR	r	.636**	1	.671**	.477**
	p	.000		.000	.000
SIC	r	.470**	.671**	1	.349**
	p	.000	.000		.001
QP	r	.422**	.477**	.349**	1
	p	.000	.000	.001	

**Correlation is significant at the 0.01 level (2-tailed).

Regression analyses were also carried out to determine to what extent each section was influenced by the rest of the sections and the model that this relationship follows. The results in Table 35 show multiple correlation coefficients (R) and adjusted R, F-, and p-values. Each R is a result of correlation between one variable (dependent variable) and the rest of the variables (independent variables). SR correlated the highest with the rest of the variables followed by SIC, TS, and QP. From the adjusted R^2, 59% of students' views about their responsibilities in the PBL process (SR) was affected by their view about the rest of the other factors. Similarly, 43% and 41% of their views about their interaction and collaboration (SIC) and teacher support (TS) are respectively affected by the rest of the other factors. Lastly, only 23% of the students' view about the quality of the problem (QP) is affected by the rest of the other sections. All these relationships are significant at the alpha level of 0.05. The results also indicate that all the relationships have clearly displayed a linear model.

Table 35

Regression analysis of CHEM 1 PBLEI sections

Dependent	R	R^2	R^2 adj	F	df	df2	p
TS	0.653	0.426	0.406	51.52	3	87	0.000
SR	0.778	0.606	0.592	44.56	3	87	0.000
SIC	0.674	0.454	0.435	24.10	3	87	0.000
QP	0.502	0.252	0.226	9.75	3	87	0.000

Equations	p		
TS = 0.606SR + 0.084SIC + 0.146QP + 0.653	SR	SIC	QP
	0.000	0.522	0.106
SR = 0.449SIC + 0.142QP + 0.303TS+ 0.522	SIC	QP	TS
	0.000	0.026	0.000
SIC = 0.022QP + 0.057TS + 0.609SR+ 1.429	QP	TS	SR
	0.766	0.522	0.000
QP = 0.204TS + 0.395SR + 0.046SIC + 1.131	TS	SR	SIC
	0.106	0.026	0.766

To determine the contribution of each construct to the variation, a linear regression model was determined using SPSS (Table 35). All the coefficients in the model are positive, indicating an that increase in one of the variables predicted an increase in the other variable. The model for TS showed a significant β coefficient (0.606, p = 0.000) only from SR, but the rest of the coefficients were not significant. This implies that the highest contribution to the variations in TS scores were from variations in

SR scores. SR scores have a significant contribution from SIC (0.449, $p = 0.000$), QP (0.142, $p = 0.026$), and TS (0.303, $p = 0.000$). The highest contribution is observed from SIC seconded by TS. This implies that how students viewed their interactions and collaboration and the quality of the problem in the PBL environment affected their view about their own responsibility. For SIC, a significant contribution was observed only from SR (0.609, $p = 0.000$). Similarly, variations in the scores of SR sections contributed significantly to the variations of the scores on the quality of the problem.

Influence of Gender on PBLEI Scores. To determine the influence of gender on students' view of the PBL environment, an independent t-test was also conducted. Kolmogorov-Sminorv carried out had KS Z for male and female participants of 0.898 ($p = 0.396$) and 0.763 ($p = 0.605$), respectively. This indicates that scores of both male and female participants were normally distributed. The descriptive data shows very little difference in PBLEI scores between male and female participants. This assertion is confirmed by inferential statistics (Table 36), which indicates probablility values above the alpha level of 0.05.

Table 36

Independent t-test for gender influence on CHEM 1 PBLEI

	Male (N = 56)	Female (N = 29)	t	p
PBLEI	4.12	4.18	0.48	0.635

Students Views: Quantitative Data for CHEM 2

Figure 8 shows a pie chart containing percentage scores for various score ranges on the PBLEI. Only one person one participant had a mean score of less than 2 and a total of 37 % of students had a score of less than 4. A high percentage of students (63%) had scores of 4 or greater. The scores imply that most students in CHEM 2 also had better attitudes toward the PBL environment as those in CHEM 1 as expected for PBL environments (Dochy et al., 2005).

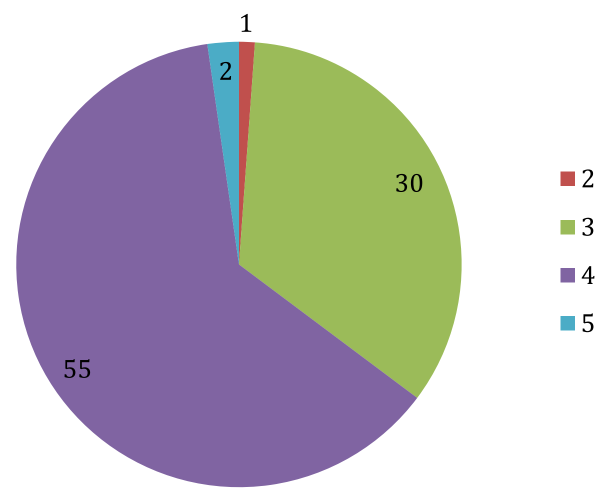

Figure 8. Distribution of PBLEI scores in CHEM 2

PBLEI section scores in CHEM 2 (Figure 9) followed a similar trend as that of the CHEM 2. Student collaboration had the highest score, followed by student responsibility. Quality of the problem and teacher support had almost similar scores. Similary, the scores were much higher than the average score of 3, consistent with what we would expect in a PBL environment. Also, in this case, students had higher views of themselves performing within the PBL environment compared to the assistance provided by the instructor. ANOVA was carried out to determine whether the differences shown in Figure 9 were meaningful (Table 37). This indicated a significant difference. The F- and the p-values (F-24.093, $p = 0.000$) indicated that the difference was also not just due to

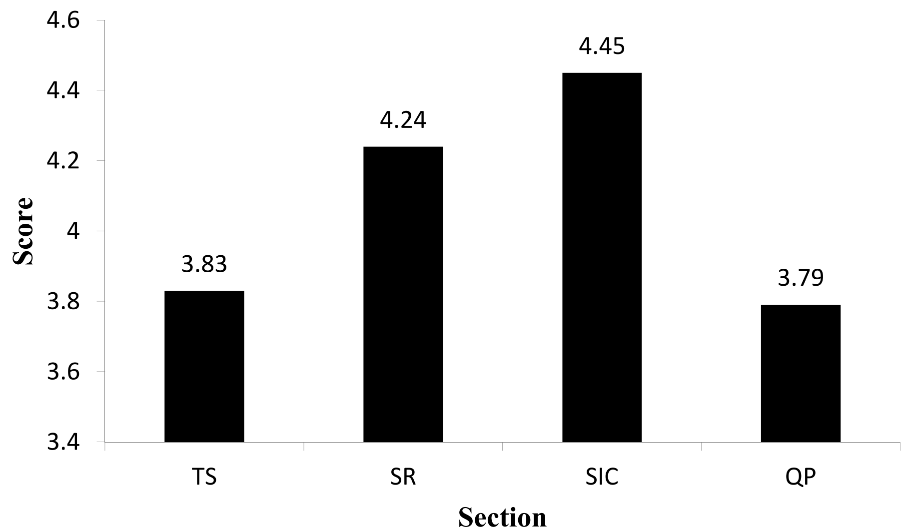

Figure 9. PBLEI scores per each section in CHEM 2

chance, but to the variations amongst the instrument sections. Post-hoc analysis indicates that the mean score of students' views of teacher support (TS) was significantly less than the mean score of their views of students' responsibility (SR) and students' interaction and collaboration (SIC). Students' views of the quality of the problem (QP) was also significantly less than their views of students' responsibility (SR) and students' interaction and collaboration (SIC). However, there was no difference between students views of quality of the problem and teacher support.

Correlation analyses were also carried out to determine the relationships amongst scores from various sections of the PBLEI survey in the CHEM 2 (Table 38). All the sections were also significantly correlated. As with the CHEM 1 results, the highest correlations were also observed between SR and SIC ($r = 0.509$) and SR and TS ($r = 0.433$).

Table 37

PBLEI ANOVA parameters for CHEM 2 PBLEI

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	27.943	3	9.314	24.093	.000
Within Groups	137.244	355	.387		
Total	165.187	358			

However, the correlations of scores in CHEM 2 were not as high athose of CHEM 1. The table shows that some correlation coefficients were significant at 0.01 level while others were significant only at 0.05 level. In CHEM 1 , all the correlation coefficients were significant at 0.01 level, indicating stronger relationships than CHEM 2.

Table 38

Pearson correlation parameters for CHEM 2 PBLEI

		TS	SR	SIC	QP
TS	r	1	.433**	.254*	.343**
	p		.000	.016	.001
SR	r	.433**	1	.509**	.381**
	p	.000		.000	.000
SIC	r	.254*	.509**	1	.262*
	p	.016	.000		.013
QP	r	.343**	.381**	.262*	1
	p	.001	.000	.013	

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

Regression analyses were also carried out to determine to what extent each section was influenced by the rest of the sections and the model that this relationship followed (Table 39). As with CHEM 1 results, SR correlated the highest with the rest of the variables followed by SIC, TS and QP. From the adjusted R^2, 37% of students' views about their responsibility in the PBL process (SR) was affected by their views about the rest of the other factors. Similarly, 23% and 20% of their views about their interaction and collaboration (SIC) and teacher support (TS), respectively, were affected by the rest of the other factors. Lastly, only 16% of the students' views about the quality of the problem (QP) were affected by the rest of the other sections. All of these relationships were significant at the alpha level of 0.05. The results also indicates that all of the relationships have clearly displayed a linear model.

Table 39

Regression analyses of CHEM 2 PBLEI sections

Variable	R	R^2	R^2 adj	F	df	df2	p
TS	0474	0.224	0.198	8.311	3	86	0.000
SR	0.622	0.387	0.366	18.10	3	86	0.000
SIC	0.515	0.265	0.239	10.33	3	86	0.000
QP	0.435	0.189	0.161	6.69	3	86	0.000
Equations				p			
TS = 0.498SR + 0.037SIC + 0.212QP + 0.687				SR 0.004	SIC 0.806	QP 0.049	
SR = 0.364SIC + 0.132QP + 0.184TS + 1.422				SIC 0.000	QP 0.044	TS 0.004	
SIC = 0.056QP + 0.019TS + 0.505SR + 2.02				QP 0.718	TS 0.806	SR 0.000	
QP = 0.209TS + 0.351SR + 0.107SIC + 1.03				TS 0.049	SR 0.044	SIC 0.475	

To investigate the contribution of each construct to the variation, a linear regression model was also determined using SPSS. All of the coefficients in the model were positive, indicating that an increase in one of the variables predicted an increase in the other variable. The model for TS showed a significant beta coefficient for SR (0.498, $p = 0.004$) and QP (0.212, $p = 0.049$), but no significant coefficient from SR. This implies that the highest contribution to the variations in TS scores was from variations in SR scores followed by that from QP scores. SR scores had significant contributions from SIC (0.364, p = 0.000), QP (0.132, p = 0.044), and TS (0.184, p = 0.004). The highest contribution was observed from SIC, followed by TS. This implies that how students viewed their interactions and collaboration and the quality of the problem in the PBL environment affected their view about their own responsibility. For SIC, a significant contribution was observed from SR (0.505, p = 0.000). The variations in the scores of SR (0.351, p = 0.044) and TS (0.209, p = 0.049) sections contributed significantly to the variations of the scores on the quality of the problem.

Influence of Gender on PBLEI Scores

To determine the influence of gender on students' view of the PBL environment, an independent t-test was also conducted. Kolmogorov-Sminorv carried out had KS Z for male and female participants of 0.685 (p = 0.735) and 0.908 (p = 0.382), respectively. This indicates that scores of both male and female participants were normally distributed. The descriptive data shows very little difference in PBLEI scores between male and female participants. This assertion is confirmed by inferential statistics (Table 40), which indicates probablility values above the alpha level of 0.05.

Table 40

Independent t-test for gender influence on CHEM 2 PBLEI

	Male (N = 56)	Female (N = 29)	t	p
PBLEI	4.14	4.00	1.33	0.187

Relationships Amongst SEBs, Attitudes, and PBLEI

Pearson correlation coefficients for attitudes and SEBs pre-test scores were determined by SPSS (Table 41). A significant correlation between attitudes and SEBs was observed only in the pre-test of CHEM 2 ($r = 0.351$, $p = 0.001$). CHEM 2 correlation had practical significance because it was greater than 0.3, however, no relationship was found between attitudes and SEBs in the pre-test of CHEM 1 ($p = 0.062$).

Table 41

Pearson correlation parameters attitudes and SEBs pre-tests

Semester	N	Pre-test Pearson r	p
CHEM 1	85	0.203	0.062
CHEM 2	93	0.351	0.001

The relationship amongst attitudes, self-efficacy beliefs, and students' views of the PBL environment was determined using the post-test scores, because that's when these were collected simultaneously. Tables 42 and 43 the show correlation coefficients and the significance levels associated with these correlation coefficients. CHEM 1 data showed a highly significant correlation between students' attitudes and SEBs ($r = 0.424$, $p = 0.000$). There was also a highly significant correlation between students' SEBs and their views of the PBL environment ($r = 0.294$, $p = 0.007$). A significant correlation was also observed between students' attitudes and PBLEI scores ($r = 0.241$, $p = 0.027$). Similarly, data for CHEM 2 shows a highly significant correlation between attitudes and SEBs scores ($r = 0.351$, $p = 0.001$) and between SEBs scores and students' views of the PBL environment scores ($r = 0.288$, $p = 0.007$). A significant correlation was also observed between attitudes and students' view of the PBL environment (r = 0.258, p = 0.015). This indicates a positive relationship amongst these three variables.

Table 42

Pearson correlations, attitudes, SEBs and PBLEI CHEM 1 (N = 84)

		Attitude	SEBs	PBLEI
Attitudes	r	1	.424**	.241*
SEBs	r	.424**	1	.294**
PBLEI	r	.241*	.294**	1

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

Table 43

Pearson correlations, attitudes, SEBs and PBLEI CHEM 2 (N = 88)

		Attitudes	SEBs	PBLEI
Attitudes	r	1	.351**	.258*
SEBs	r	.351**	1	.288**
PBLEI	r	.258*	.288**	1

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

Data Modeling

Studies were done to establish a model to indicate relationships amongst students' attitudes toward chemistry, SEBs, and PBLEI views. To establish this model, regression analyses were conducted amongst these three constructs. In total, three regression models were formed. In each case, one of the constructs was chosen as a dependent variable while the other two were set as independent variables. The aim was to determine how much the changes in one of the construct could be explained by the other two constructs.

Table 44 shows results of the multiple correlation coefficient (R), probability from the multiple correlation coefficient (R^2), F, and the p value of the model.

The data show that 21% of the variation in self-efficacy beliefs could be explained by the variations in students' attitudes toward chemistry and students' views of the PBL learning environment. The data also show that 19% of the variation in attitudes scores could be explained by the combined variations in SEBs and PBLEI scores. Similarly, 10% of variations in the PBLEI scores are explained by the combined variations in students' attitudes and SEBs. All these probabilities were significant at the alpha level of 0.05.

Table 44

Regression data (CHEM 1)

Dependent	R	R^2	R^2 adj	F	df	df2	p
SEB	0.468	0.212	0.199	11.340	2	81	0.000
Attitudes	0.441	0.194	0.174	9.772	2	81	0.000
PBLEI	0.321	0.103	0.081	4.646	2	81	0.012

Equations	p	
SEBs = 0.375Attitudes + 0.204PBLEI + 1.544	*A*ttitude	PBLEI
	0.001	0.047
Attitudes = 0.386SEBs + 0.127PBLEI + 2.548	SEBs	PBLEI
	0.001	0.227
PBLEI = 0.142Attitudes + 0.234SEB + 2.883	Attitude	SEBs
	0.227	0.047

To determine the contribution of each construct to the variation, a linear regression model was determined using SPSS. All the coefficients in the model were positive, indicating that an increase in one of the variables predicted an increase in the other variable. The model for SEBs showed a higher coefficient from the contribution in attitudes scores (0.375, $p = 0.001$) than from PBLEI scores (0.204, $p = 0.047$). The data indicated that for each unit change in attitudes score, the SEBs score changed by 0.38 units if PBLEI was held constant. Similarly, for each unit change in PBLEI score, the SEBs score changed by 0.20 units when the attitudes variable was held constant. This indicates that attitudes contribute more to the combined effects on the variations of students' SEBs than PBLEI scores. However, both contributions were significant at the alpha level of 0.05.

The attitude model indicated a higher contribution from SEBs (0.386, $p = 0.001$) than from PBLEI views (0.127, $p = 0.227$). This also indicated that for every unit change in SEBs, attitudes changed by 0.39 units. Similarly, for every unit change in the PBLEI variable, attitudes changed by 0.13. A significant contribution, in this case, was observed only for the contribution of SEBs. Lastly, the PBLEI model showed a significant contribution only from SEBs (0.234, $p = 0.047$), but no significant contribution from attitudes scores (0.142, $p = 0.227$). In general, the results have shown that SEBs scores contributed to the explanation of variations for both attitudes and PBLEI scores. Attitudes and PBLEI scores, however, do not significantly explain the variations of each other when combined with the contribution of SEBs.

Table 45 shows regression parameters from CHEM 2. The data shows that 17% of the SEBs scores are predicted by the combined attitudes and PBLEI variables, 15% of attitudes scores are predicted by the combined PBLEI and SEBs variables, and 11% of PBLEI scores are predicted by the combined attitudes and SEBs variables. The significance test indicates that all these relationships are different from zero ($p < 0.05$). The model for SEBs also showed a higher coefficient from the contribution of attitudes (0.297, $p = 0.005$) than from PBLEI (0.211, $p = 0.042$). This also indicates that attitudes contribute more to the variations of students' SEBs than PBLEI.

Table 45

Regression data (CHEM 2)

Dependent	R	R^2	R^2 adj	F	df	df2	p
SEB	0.406	0.165	0.145	8.389	2	85	0.000
Attitudes	0.387	0.150	0.130	7.496	2	85	0.001
PBLEI	0.333	0.111	0.090	5.293	2	80	0.007

Equations	p	
SEBs = 0.297Attitudes + 0.211PBLEI + 1.313	*A*ttitude	PBLEI
	0.005	0.042
Attitudes = 0.302SEBs + 0.171PBLEI + 2.843	SEBs	PBLEI
	0.005	0.106
PBLEI = 0.179Attitudes + 0.225SEB + 2.836	*A*ttitude	SEBs
	0.106	0.042

However, both contributions are significant at the 95% confidence level. The attitude model indicates a higher contribution from SEBs (0.302, p = 0.005) than from PBLEI views (0.171, p = 0.106). A significant contribution, in this case, was observed only for the contribution of SEBs. The PBLEI model also shows a significant contribution only from SEBs (0.225, p = 0.042), but no significant contribution from attitudes scores (0.179, p = 0.106). In general, the results have also shown that SEBs scores contributed to the explanation of variations for both attitudes and PBLEI score. However, attitudes and PBLEI scores did not significantly explain the variations of each other when combined with the contribution of SEBs.

The Qualitative Data Results

The interviews were conducted at the end of each PBL session. These interviews were aimed at determining how the students felt about PBL by determining the attributes that led to their views of the PBL environment. The second aim was to corroborate and expand upon the findings from the CAEQ and PBLEI through the interview questions. In this case, the aim was to determine whether students felt that they improved both their SEBs and attitudes after undergoing PBL instruction.

Fifteen students were interviewed spanning from the Spring 2012, Summer 1 2012, Fall 2012, and Spring 2013 semesters. The results presented here are a compilation of all the data from the aforementioned semesters and pseudonyms have been used for participants names. After the analysis of the interview data, codes were developed through the constant-comparative method. HyperResearch was used to organize the codes, and themes were developed through thematic analysis of the coded data. The results are presented in line with the research question in this study as follows:

PBL and SEBs Change

This section answers the research question "*What is the relationship between participarting in a PBL unit and students' SEBs in chemistry*?" From this question the main theme covered students' confidence in chemistry. Three sub-themes described this theme as follows: confidence in chemistry; ability to plan and conduct experiments; and confidence in conducting undergraduate research. The major sub-themes are presented below.

Confidence in Chemistry

Some of the interviewed students felt that PBL generally improved their confidence in chemistry in general. For instance, Jacob felt that his confidence improved because the PBL lab provided a new experience, *"I do feel a lot more confident just* *because it gives you that experience you haven't had before in chemistry."* Similarly, William felt that being taught the ability to determine what you are finding out using the given equations improved his confidence in chemistry, *"Mainly because you have to. You have the equations that you are using, but you have to know what you are finding, then where to put it in the equation, where most labs are, ok you found this value, this is where it goes."* Lucas also felt that he was more confident in his abilities to set up his own experiment after undergoing the PBL instruction, *"I definitely feel more confident and say now I can, with some time, set up a good experiment and figure out what's gonna work and what's not gonna work next time."* To Cherie, the confidence arose because she felt that the PBL activities provided a better understanding of chemistry and its applications *"I think it (PBL) just gave me a better general understanding of chemistry and how you apply it so hopefully I think that will help me in the future chemistry classes."* However, Daniel felt that he was already confident about lab processes and the lab did not affect his confidence at all. Daniel felt that the PBL lab set up was confusing and harder to deal with. Nevertheless, he acknowledges that the PBL labs were generally better than the usual labs.

> Daniel: *Well I'm pretty confident myself in lab processes. I think that lab set up, it almost discourages a little bit just because of the confusion and it's a little harder to approach ... This was more of you are doing this and try and do this but with all overwhelms that we put in there, it really wasn't a great experience. It was better than the regular chemistry labs that we were doing before.*

Confidence in Ability to Plan and Conduct Chemistry Experiments

Generally, the students also felt that the PBL environment improved their ability to plan and conduct chemistry experiments. The students felt that PBL provided in-depth instruction, it helped with organization for laboratory activities and timing of the experiments, and provided them with more responsibilities as students. These factors raised the students' confidence in planning and conducting chemistry experiments. For instance, Jacob felt that PBL improved his ability to plan for the experiment. In this case, he felt that PBL gave him an opportunity to plan and determine what variables to deal with before the actual experiment.

> Jacob: *Well, I had the experience for experiment planning before with like physics lab and other chem.labs. PBL was a lot more in-depth and it helped me to really be able to find all the different variables and account for them before you actually did the experiment. So if you get some unfamiliar results, you would definitely have to run back through all your variables and say, oh yeah, that's where I was wrong, I should probably fix that for next rounds.*

William also agreed that PBL improved his confidence in planning and conducting chemistry experiments. He felt that PBL helped him understand that through proper organization and team work, experiments can become a lot easier.

> William: *I think it helped [improving confidence] quite a bit. I mean, the first time that we run the experiment, we were disorganized. It took us four or three hours and even then we were rushing for time and trying to get done. Then the second time we were more organized and had more clear procedure, we knew what we were supposed to be doing worked more as a team and kind of done a lot faster.*

Lucas felt that PBL helped improve his confidence in his ability to plan and conduct chemistry experiements because he recognized that with time he could improve upon his experiments and conduct the activities within a shorter period of time. He felt that his ability to recognize the mistakes and improve upon them improved his confidence to plan and conduct chemistry experiments.

> Lucas: *Over the weeks it helped me learn to be more precise and helped me to conduct experiments in much shorter amount of my time. I recognized, you know, mistakes that I was making, I was able to crack them so that when we did the final experiment we did it quickly and it all went pretty well.*

Cherie felt that being given more responsibility than normal improved her ability to plan and conduct experiments, *"It gave us a little bit more responsibility than normal so we learned how to plan and guide ourselves in doing the experiment more than the former structured labs that we started with."*

However, Daniel felt that the PBL activities had no effect on his confidence in planning and conducting chemistry experiments because of having limited trials on which to improve on. He felt that just two days of experiments did not give the students sufficient time to try out some variables.

> Daniel: *I don't think this one did as much just because we were limited on the trials and the fact that we can do one trial per day made it so that the first day we had to get our data and the second day we really, we could've changed some things to make our process better, but anything that we will change will make our data inconsistent between the two days. So it was really the struggle between whether we change and try to improve or do we have consistency of our data.*

Confidence in Conducting Undergraduate Research

In terms of conducting undergraduate research, genereally students felt that PBL had an effect on their confidence because PBL was an informative experience that made them become more independent and provided them a good practice for undergraduate research. William felt that PBL made him realize that he could do more in undergraduate research. Although he had been interested in undergraduate research before, he never had the opportunity to do it until the PBL activity, *"I have been really interested in doing undergrad research. This is the first one I've ever done and it was pretty fun, pretty informative, and a good experience. I think I can do more."*

The students also felt that PBL improved their confidence in conducting undergraduate research. For instance, Lucas felt that PBL was frustrating, but at the end made him feel more confident about his ability to conduct independent research *"I would* *say that it initially kind of frustrated me because it was more difficult, but it makes me more confident because I know that I can be independent and that also I can work with someone."* In addition, Isabel felt PBL made them practice doing research, and this improved her confidence in conducting undergraduate research, *"Just the practice and the experience doing the lab and creating the questions and determining all values and variables that change, I think the whole just need practice doing that."* Cherie believed that PBL enhanced her understanding of the experimental process, hence this improved her confidence in conducting undergraduate research, *"It gave me a little bit more confidence because I have a better understanding of what you would do to start and end an entire experiment."* William praised the PBL experience stating that this is the first time he had been in contact with real undergraduate research, *" I have been really interested in doing undergrad research. This is the first one I ever done and it was pretty fun, pretty informative, and good experience…I think I can do more."*

PBL and Attitude Change

This section answers the research question "*What is the relationship between participarting in a PBL unit and students' attitude towards chemistry*?" The interview questions in this section specifically sought students attitude towards chemistry, chemists, and chemists roles in the society. Students indicated that the PBL environment changed their attitudes toward chemistry, chemists, and their roles in society. Jacob felt that PBL provided insights on how chemists conduct their experiments and the thinking involved in the process. This increased his respect for chemists.

> Jacob: *It definitely gave me a lot more experience and insight into what experimental chemists actually do, because, like our TA was saying, this is pretty much what we do in research because you have no idea of how these variables*

will change the reaction, so you have to proceed pretty cautiously for certain experiments. It just allowed me to have more respect for chemists.

William agreed with Jacob after observing the obstacles that chemists face to solve problems. The difficulties that students faced in creating their own procedures and searching for information made him appreciate the work of chemists.

> William: *Again, a lot more respect for people that create their own procedures and all that because it was pretty difficult at first to come up with what exactly we had to do and as far as chemistry in general, I really learned quite a bit as far as everything that goes into it what all it can do, how you can look at it in order to test for various things to produce mass quantities.*

Lucas corroborated his collegues' views, as he felt that the PBL labs made him realize that there is a lot more to chemistry than he previously thought. Although he initially had respect for chemists, he felt that the PBL activities reinforced that respect because he felt chemistry is a lot of work and what chemists do have direct impact on the society.

> Lucas: *It's made me realize that chemistry is, there is a lot more to it than I thought there was before and so I realized that there is a lot more to learn that I hadn't previously known and I definitely, at least, have more respect for chemists. Well, I mean, I kind of already held these views but it reinforced them that for one it's a lot of work as a chemist, it's a lot of work and, you know, I respect that and the things that chemists are doing in the lab can have a direct impact and just to a normal member of society and just every consumer.*

To Cherie, understanding that what chemists do is not just random science, but things that are important in real life reinforced her belief in the usefulness of chemistry. The PBL activities showed her that chemists are actually doing work that can be used in every day life.

> Cherie: *Same thing, like kind of really important in that what they do is not just random science. They are actually doing things that are involved in what we all do. I think it reinforced the idea that chemistry is an important practice to help things like improving fuel economy and things like that so, basically, chemistry is*

really important in that it's involved in the things we use every day.

However, some students felt that PBL did not change their attitudes toward chemistry. For instance, Daniel felt that he already had a positive attitude towards chemistry and the activities did not affect his attitude, while Isabel felt that the experiment was not about society and so did not affect her views.

Students' Views of the PBL environment

This section answers the research question "*What is the students' views of the PBL environment*?" In this category, students felt that generally the experience in the PBL laboratories was better than that in the traditional labs. They felt that PBL enhanced their independent thinking, improved their ability to solve real world problems, increased their enthusiasm, and increased their ability to reason. Despite these positive outcomes, they also indicated that PBL was difficult.

Generally PBL was perceived more positively than Traditional Labs

When asked to compare PBL and the traditional labs, most students that were interviewed felt that PBL activities were better than those involved in the traditional labs. The students felt that PBL was better because it brought something new to their learning. Some students felt that PBL was better because it encouraged real world applications and forced students to do their own research. For instance, Harry felt that PBL connected better with the real world than the traditional labs.

> Harry: *We are pretty into context and with the articles and biodiesel these fuels we can use right now. It's kind of a nice segue into taking something in the laboratory, applying to the real world and seeing that connection better than the traditional way.*

Similarly, Dakota felt that PBL activities were a good preparation for graduate and medical school and helps students to understand the role of chemistry in society.

> Dakota: *But if you are looking at applying to real life which you want because especially if you go on to graduate school and medical school you have to apply it really, actually, everyone should know how to apply it. So problem based is definitely helpful in the long run for understanding why we need chemistry in the first place.*

Some students also felt that PBL provided them with an opportunity to do research on their own to better understand the activities they were doing. For instance, Christine felt that traditional labs do not provide them with that experience as alluded to in the quote below:

> Christine: *I definitely feel it has. I went across stuff I really didn't understand what we were actually doing and in the normal labs we don't have to do that kind of stuff. We don't really have to know what we are doing but in this research we gained a concept of real world problems and what we can do to fix them.*

Similar sentiments were reported by Harry and Tom. These students felt that doing their own research improved their understanding of the concepts behind the lessons. To them, action was a lot better than just observing as exemplified by Harry below:

> Harry: *I think it's better because, like, it forces students to do more research on their own. You have to really understand if you're gonna build your own parameters or adjust something. You have to really understand, you know, action is a lot deeper than observing something from the lab manual that's already written for you.*

PBL Enhances the Independence of Students

Some students felt that PBL encouraged their independence in learning because it taught them self-reliance. In this case, the students felt that having an opportunity to fix things by themselves, and do research to find out more about a problem helped to improve their independent learning. For instance, Steve felt that autonomy and creativity made PBL appealing, *"Yeah, it was different because we had to like fix our own problems and we had to come up with new ways to make things work where as normal labs they just told you everything to do."* Similarly, Jessie acknowledged that the TA helped with the learning process, but it's basically the student who did most of the work and this made students get better with more practice.

> Jessie: *I think the strategy that I believe, like, a chemist teaches himself, even though there is like a TA and you gonna ask the TA but you gotta teach yourself to improve this technique the more you read the more you get better, the more you practice.*

Accoriding to Harry, PBL "*teaches you how to do research on your own, find out more about what you are researching and teaches you to take more self initiative*."

PBL Improves Ability to Solve Real World Problems

One important attribute of PBL is its ability to foster problem-solving skills in students. From our interviews, students had the view that PBL was a good instructional procedure because it improved their ability to solve real world problems. For this attribute, students felt that the traditional lab instruction just followed a rubric and did not teach students how to solve problems. Some students believed that being given an opportunity to come up with their own procedures influenced how they viewed their ability at solving real world problems. For them, PBL was not artificial because students solved real-life sensors or biodiesel problems. Students felt that this experience afforded them an opportunity to face problems similar to those encountered in real-life situations. Jessie felt that having to develop their own procedure helped them to learn better because they were involved in the activities

> Jessie: *My opinion like, I like the PBL lab since we have our own protocol, I mean procedure; we can improve that; we do whatever we like. And this way, I think we are gonna learn better than the other procedure which is like the methods here and the whole thing you have to do is just read and follow the procedure.*

Tom felt that PBL was better at teaching skills in solving real-life problems because it looked more authentic than the artificial activities he encountered in the traditional labs.

> Tom: *I think it's (PBL) good at teaching skills in solving real life problems because it doesn't seem artificial. Where as in, like, traditional lab approaches, it's completely artificial. Everything is set up one way, you just follow a set of procedures and directions. Here, you are actually kind of designing your own procedures within, like, margin so that you don't screw everything up completely and blow things up.*

Similarly, Oliver felt that the education system did not do a good job at preparing students for real-life applications of their educational activities. He, however, felt that PBL was the right step towards encouraging application of classroom work toward real life situations as exemplified below:

> Oliver: *I definitely say PBL is better at teaching skills in solving real life problems. In the regular labs that we do, you are not really thinking of how you would apply them to real world problems, so there is not really as we are going through our education system, we don't really learn a lot of stuff about applying anything to real world situations. We are just learning how to do it itself so I think it helps increase the skill of solving real life problems a lot.*

Lastly, Sidney felt that the problems they encountered during their PBL activities demonstrated to them how the real world works. In this case, they had to figure out how to deal with the problems on their own as Sidney states below:

> *Probably the PBL because, at least in our experiments, we came across different problems when doing the procedure, and so we had to figure out ways to fix it, and so, I feel like in real life we have to figure out what to do when things go wrong instead in the traditional lab, like, so you know what's supposed to happen where as in this we weren't sure what's gonna happen.*

PBL Increased Students' Enthusiasm

Students felt that they were more enthusiastic about the PBL labs compared to the usual labs because they saw the purpose of doing the PBL labs. The students felt that the PBL labs were interesting, and it was much easier to understand the activities because there was a purpose for carrying out the lab. Some students felt that the activities made them interested in doing more. In summary, the students felt that they were actually doing something. For instance, Christine was looking forward to these labs as she pointed out:

> Christine: *For the first time I really enjoyed doing the lab. Every 8 am was like I can't get up and go to the lab right now because we are gonna not do anything that special but this time we spent time out of class doing it; my mind was really into it. For the first time, I thought like we were actually doing something. I feel like with the general normal laboratory procedure we go in, we do it, and then we don't necessarily take anything away from it.*

Oliver felt that the lab was interesting because it had a purpose and hence made him more inclined to do more *"I felt like the PBL is interesting and I felt like I had a purpose to do what I was doing so it makes me actually want to go out and do more stuff."* These sentiments were corroborated by Tom who also stated that he liked PBL because he felt they were actually doing something worthwhile, *"I think that the problem based learning was more interesting because, compared to the other labs we did, we were actually doing something that we haven't done before."* On the other hand, Harry felt that it was much easier to understand something if you have a reason to do it. *"Definitely, again it's much easier to understand what you are doing, conceptualize it, and be interested in it if you have a reason why other than you are supposed to get a degree."* These students agree that having a purpose was a driving factor in their enthusiasm toward PBL.

PBL Improves the Ability to Reason

The students felt that PBL activities had the potential to improve students' abilities to reason. Just the chance to solve real world problems gave the students opportunities to involve a lot of thinking because they had to think how to solve the problems, and how to figure things out. The students felt that the traditional labs, which were exemplified by a "recipe" procedure did not afford them the opportunity to reason. According to Oliver, the traditional labs did not encourage them to use their reasoning abilities as stated below:

> Oliver: *In usual labs, students can solve problems without a whole lot of thinking and the reasoning behind what we're doing, while in problem based learning we had to plan ahead and do the background research first and actually figure out what we're trying to do before we were able to try to do it.*

In addition, Harry felt that PBL improved his ability to reason because *" It [PBL] teaches you to think about things more from a perspective of problem solving rather than just following directions."* Similarly, Christine felt that the traditional labs lacked the capacity to improve the ability to reason because students were not presented with a problem but just a procedure to use.

> Christine: *Yes absolutely with the titration, I don't think, with the other labs we were presented with a problem necessarily, we were presented a lab procedure, and we did it and then we solved like using an equation but I don't think we were trying to figure something out. We were just doing an experiment and then calculating some stuff that didn't really matter to us.*

PBL is Difficult

Even with all the positive aspects of PBL presented above, a number of students felt that PBL was difficult to get used to, especially at the beginning. Some students felt that leaving the responsibility of learning to students was stressful, while others felt that

PBL was frustrating at the beginning, especially that a lot of material had to be covered within a specific period of time. For instance, Steve reported that sometimes they could not finish some activities because they didn't understand what to do.

> Steve: *And this, like I said, is just a simple lab but like having everything on us was very stressful and then we had to come up with our own results and like present it and make it sound like we knew what we were doing. We didn't really sometimes.*

Dakota corroborated this assertion, but felt that it's only harder at the beginning and becomes easier over time.

> Dakota: *At first is harder but afterwards I think it's easier because first you apply directly what you know from the lecture and use that and apply it to, like for instance, biodiesel fuel which is relative to our society today in terms of economy and environment. So I think it's good.*

However, Dakota felt that the PBL activities were too involved, causing the focus of the lesson to be lost in the activities.

> Dakota: *In terms of like just in the class, I think the work like package and stuff, I think it's good because the questions made you think but especially as you have to finish a pack every day, I think it should be you know, not so repetitive. I think the student will know to keep those in mind and if you show in like daily work that it's easier for them to, you know, say, ok I can do this; I don't have to worry about all this.*

Suggestions for Improvement

When asked about suggestions for improvements, the students had varied responses. Some students felt that the background provided for the activities was not sufficient whilst other students felt the need for more structure in the PBL activities. Jacob suggested that the activities should be extended to enable students get accustomed.

> *My one big suggestion would be to extend it for another day, we have plenty of time to prepare for it, we definitely could have used more time actually*

performing the experiments in the lab and like right now our lab for this week is just cleaning up the lab which could have been done after the last presentation.

Dakota felt that students were overwhelmed with various activities during the PBL. She felt that having a lot of materials made students lose focus of the purpose of PBL.

In terms of like just in the class, things like small things like, I think the work like package and stuff, I think it's good because the questions make you think but especially as you have to finish a pack every day, I think it should be you know, not so repetitive. I think the student will know to keep those in mind and if you show in like daily work that it's easier for them to you know say, ok I can do this I don't have to worry about all this. And talking about it like between other groups is always good because discussion is easy for any student, they can talk about it forever but just in terms of small work, I think it should be more exact to the point because they can remember like why do we do this. If you present to them a large package that's something like more work in there instead of just more thinking they are just like no I don't wanna do this. They don't see the big picture.

Chapter 4 Summary

PBL's influence on students' SEBs in and attitudes toward chemistry of general chemistry laboratory students has been investigated. In addition, this study also investigated the students' views of the PBL environment. The CAEQ has been used to determine the changes in both attitudes and SEBs scores while the PBLEI has been used to investigate the students' views of the PBL environment. Kolmogorov-Sminorv tests were used to investigate the normality of the distribution of attitudes, SEBs, and PBLEI scores. Independent t-tests and ANOVA were used to investigate the influence of confounding factors such as gender, ACT scores, GPA, number of chemistry courses, and students' major. Correlations and regressions were used to establish relationships amongst PBLEI variables and amongst attitudes, SEBs, and PBLEI responses. Interviews were used to augment the qualitative data.

Generally, only the instructor and the number of chemistry courses influenced the students' SEBs scores at either pre-, post-tests or both. The only influence for the attitude scores was the number of chemistry courses. Paired sample t-tests indicated that PBL improved students' SEBs at alpha level of 0.05. No improvement was observed in students' attitudes toward chemistry using the CAEQ. However, interview responses showed that the students felt both more confident in chemistry and had a positive view of chemistry, chemists, and their roles in society after undergoing PBL instruction. The qualitative data also showed that the students' had a positive view of the PBL environment.

Correlations results indicate that there was a significantly positive relationship amongst the PBLEI factors, indicating that improving quality of the problem, teacher support, students' responsibilities, and students' interaction and collaboration is essential because these factors work together. Regression results also indicate a relationship amongst the factors. Correlations and regression analyses showed similar results in the relationship amongst attitudes, SEBs, and PBLEI responses. SEBs significantly contributed to the explanation of both attitudes and PBLEI linear models. However, attitudes and PBLEI scores did not significantly contribute to each other's models.

CHAPTER 5

DISCUSSIONS, CONCLUSIONS AND IMPLICATIONS

Introduction

Chapter 5 presents the discussion, implications, and conclusions of the study. The aim of the results and data analysis was to answer the four research questions that guided the study:

- What is the relationship between participation in a PBL chemistry laboratory unit and students' attitudes towards chemistry?
- What is the relationship between participation in a PBL chemistry laboratory unit and students' self-efficacy beliefs in chemistry laboratory?
- What are students' views of the PBL environment?
- What is the relationship between chemistry students' views of the PBL environment, their self-efficacy beliefs, and their attitudes?

The discussion of the quantitative data starts with the SEBs scores followed by the attitudes scores. Then the PBLEI is discussed including the correlations and regressions amongst the PBLEI factors. This is followed by the discussion of the results from the relationships amongst attitudes, SEBs, and PBLEI scores. Finally, the qualitative data is discussed, comprising the attitudes, SEBs and students' views of the PBL environment. The discussion has been outlined in terms of assertions to bring coherence to the organization of data. The assertions are as follows:

(1) Participarting in a PBl laboratory unit increased students' self-efficacy beliefs;

(2) While qualitative data indicates no improvements in students' attitude towards chemistry, the qualitative data indicates an improvement;

(3) Students had views of the instructional strategy as expected of PBL environments; and

(4) Positive relationships are observed between attitudes, SEBs, and students' Views of the PBL environment.

PBL and SEBs in Chemistry

The first assertion for this study was that '*participarting in a PBL laboratory unit increased students' Self efficacy beliefs in chemistry.*' This section presents a discussion of this assertion starting with the influence of the confounding variables, quantitative, and qualitative data.

The influence of confounding factors such as ACT scores, student major, GPA, number of chemistry courses, and gender was determined. Generally, the confounding factors such as ACT, student major, and GPA did not influence attitudes, SEBs, or PBLEI scores. This indicates that these confounding variables may not be good predictors of students' attitudes toward chemistry, SEBs in chemistry, and students' views of the PBL environment. In CHEM 1 the four instructors were Joseph, Norma, John, and Jeff while in CHEM 2 the instructors were Agatha, Norma, and Jeff. The influence of instructors was observed in the SEBs scores in CHEM 1 and the pre-test of CHEM 2. A post-hoc analysis was done to determine what mean scores were responsible for the observed differences. This post hoc analysis showed that in all the cases, the mean scores from Jeff's lab classes were consistently lower than those from the other instructors. However, this difference disappeared in the post-test of CHEM 2. Probably, having used PBL for two consecutive semesters, Jeff improved his confidence in running the PBL activities and this may explain why he was able to catch up with the rest of the other instructors.

The range of the number of chemistry courses previously taken for the two semesters was 1 – 5. Therefore, ANOVA was conducted to determine the influence of this number of chemistry courses to students SEBs. The influence of the number of chemistry course was observed in SEBs scores from the CAEQ. Experiencing chemistry courses for longer periods of time likely improved the students confidence in themselves. However, during the post-test of CHEM 2 students, this advantage disappeared. Likely, the students with two or less courses were able to catch up in their SEBs.

Results from the SEBs data have shown that there was a significant increase in mean scores on the self-efficacy scale between pre- and post-tests. This indicates that the PBL learning environment has the potential to improve students' SEBs in chemistry. This is not surprising, as Jungert and Rosander (2010) and Senay (2010) claimed that a conducive teaching/learning environment can foster the development of students' self-efficacy beliefs. PBL instruction is one of those conducive learning environments, as proposed by Keller (1987), and as was also shown by Moos and Azevedo (2009), Nawago et al. (2007), and Dunlop (2005). Furthermore, PBL has the tenets of constructivism that (1) encourages an authentic task, (2) designs the learning environment to support and challenge the learner's thinking, and (3) supports the learner in developing ownership for the overall problem or task (Savery & Duffy, 2001). This environment may be responsible for the improvement of students' SEBs.

It is not surprising that students improved their SEBs on the item "*Reading the procedures for an experiment and conducting the experiment without supervision*" because the activities in PBL requires them to do literature readings to understand their activities. Similarly, proposing a meaningful question is part of PBL activities (Hmelo-Silver, 2004), hence their improvement is not surprising. Surprisingly, CHEM 1 data shows that there was no improvement in students' confidence in their ability to design and conduct chemistry experiments. One of the most important aims of PBL is to enable students identify a problem and design a process to solve this problem, thus we expected an improvement of their SEBs on this item.

In CHEM 2, students felt that they were more confident in applying theory learned in class for laboratory experiments and designing and conducting experiments. This was not the case with the CHEM 1 students. CHEM 2 class did PBL activities based on the biodiesel unit. These activities had more application of theory from the reaction kinetics such as the roles of catalysts, temperature, and amounts of substances and relation to course content compared to the activities from the sensor unit. Therefore, it's not surprising that CHEM 1 students did not improve their confidence in applying theory to laboratory activities. This experience provided the CHEM 2 students with an opportunity to apply their knowledge about reaction kinetics, but without direct ties to general chemistry I content, CHEM 1 students had limited opportunities to apply course content to the sensors lab.

Contrary to the CHEM 1 data, students in CHEM 2 had an improved confidence in designing and conducting a chemistry experiment. This finding matches with one of the major aims of PBL, which is to be able to design and conduct research to solve an ill-structured problem (Belt et al., 2005). The feeling of confidence that the students displayed here is very important because Bandura and others have shown that confidence in an individual's ability to perform tasks influences the accomplishment of those tasks (Bandura, Adams, & Beyer, 1977; Bandura, Adams, Hardy, & Howells, 1980). Therefore, these results indicate that students will be more likely to accomplish the tasks mentioned above due to their improved SEBs.

Gender did not influence students' SEBs in chemistry in this study. Results from this study agree with Rose (2003) and Smist (1993), who also found no difference between the SEBs scores of male and female students in college chemistry except on lab skills where male participants scored significantly higher than females. These results contradict those of Busch (1995) who found a difference in mean SEBs scores between male and female participants doing computer sciences. Using the same CAEQ on freshman chemistry students in New Zealand, Dalgety et al. (2009) found that male participants scored significantly higher on most self-efficacy items than female participants. These results disagree with those by Majere, Role and Makewa (2012) who found that female students had a significantly better self-efficacy beliefs in chemistry than boys.

The qualitative data corroborated the findings from the quantitative section on the relationship between PBL and students' SEBs. The students reported that PBL improved their SEBs in chemistry. In this case, PBL improved their confidence in chemistry in general, in conducting chemistry experiments and undergraduate research in particular. These results corroborated the quantitative data, which also indicated an improvement in the students' SEBs. We predict that the experience of solving an ill-structured problem that models real life experiences gave them an appropriate context for real life chemistry experiments and experience with undergraduate research. This improvement in SEBs may also come from improved student intrinsic motivation as reported by Hmelo-Silver (2004). Solving problems with practical relevance improved students motivation to do chemistry experiments and undergraduate research, which consequently may have improved their confidence in doing these activities. Through journal responses, Dunlop (2005) also observed a change in students' SEBs for software professionals. This is not surprising because PBL has a potential to improve life-long competencies that include (Engel, 1991):

- Dealing with problems and making reasoned decisions in unfamiliar situations.
- Reasoning critically and creatively.
- Adopting a more universal or holistic approach.
- Identifying personal strengths and weaknesses, and undertaking appropriate remediation (self-directed learning and metacognitive skills).

Implication for Teaching

Results from this study have indicated that there is a positive relationship between PBL and students SEBs. Bandura (1986, 1993) has argued that SEBs have a positive effect on students' cognitive development. Research has also shown that students with higher SEBs put more effort into their schooling because they are higly motivated (Bandura, 1997; Chowdhury & Shahabudd, 2007; Zimmerman & Kitsantas, 1997). Furthermore, research found that students with higher SEBs have improved conceptual understanding and classroom performance compared to students with lower SEBs (Andrew, 1998; Ferla et al., 2009). Instructors, therefore, must understand that PBL has the potential to improve students' motivation and classroom performance due to improved students' SEBs.

PBL and Attitude Towards Chemistry

The second assertion for this study was that 'while qualitative data indicates no improvements in students' attitude towards chemistry, the qualitative data indicates an improvement.' This section presents a discussion of this assertion starting with the influence of the confounding variables, quantitative, and qualitative data.

Of the confounding variables, ACT, GPA, students' major, number of chemistry courses, and gender, only the number of chemistry courses influenced students' attitudes toward chemistry. We predict that having more experience with chemistry courses improved students' attitudes. Our results indicated that instruction through PBL did not influence students' attitude towards chemistry in either CHEM 1 or CHEM 2. These results councur with those by Erdem (2012), who found that PBL did not influence students' attitudes toward science. Similarly, Langen and Welsh (2006) found that PBL did not influence students' attitudes towards a biology course about the environment. In chemistry, Gurses et al. (2007) also found no significant improvement of students' chemistry attitude mean scores. Recently, Tosun and Senocak (2013) also found no significant correlation between PBL and secondary school prospective teachers' attitudes toward chemistry. Our results contradict those by Lou et al. (2011), Ferreira and Trudel (2012), and Chen and Chen (2012), who found that PBL improved students' attitudes toward science, technology, engineering, and mathematics (STEM). Attitudes are static behaviours (Borg & Gall, 1983), and hence it is possible that because the PBL activities took only four lab sessions, the attitude change would not be easily observed. Furthermore, there may be a possible misalignment between the instrument and the instruction. The instrument appears to have a lot of questions that were not directly related to the classroom activity (e.g. chemists are athletic). Second, there could have been change but the instrument was not sensitive to pick it up. However, when the data was stratified to determine the changes in attitudes for students with lower and higher initial attitudes, it was found that students with initial attitude scores of less than 4.5 (n = 19 out 85, p = 0.04) in CHEM 1 and those with initial attitudes scores of less than 5 (n = out of 93, p = 0.02) in CHEM 2 had significant improvements. Therefore, it's possible that, overall, most students already had high attitudes towards chemistry and hence were unlikely to have a significant improvement after PBL instruction.

In addition, gender did not have any influence on students' attitudes scores. These results agree with Majere et al. (2012), who found a similar nonsignificant trend with females having higher mean attitude scores than males. Neathery (1997) also found that gender did not affect secondary school prospective teachers attitudes toward chemistry. Our results contradict those by Ekici and Hevedanli (2009), who found that girls had significantly better attitude scores than boys in high school biology. For this study, however, female participants had higher mean attitude scores than male participants in both semesters, although the differences were non-significant. Our results, therefore, imply that attitudes toward chemistry do not depend on students' gender.

While no significant in participants attitude towards chemistry was observed from the quantitative survey results, during the qualitative interviews the students reported an improvement in their attitudes toward chemistry, chemists, and their roles in society. The students expressed interest in what chemists do, and they reported an increased respect for the role of chemists after undergoing PBL instruction. This is possibly because the students had an insight into what chemists actually do in their labs. The challenges that the students faced in their PBL labs likely made them realize how resilient chemists are in their job. Furthermore, the students understood the usefulness of chemistry and chemists to the real world life. The activities that the students undertook in these PBL labs had direct impact on the current conversation of diet and foodstuffs, and energy. Through these activities, the students realized that chemistry is indeed useful in their lives. An improved students' attitude is important because it has a potential to raise students' awareness of the importance of chemistry and hence improve the likelihood of becoming chemistry majors.The qualitative results had more positive outcomes than their qualitative counterparts. The qualitative interviews provided the students with opportunities to reflect upon the PBL environment and their experiences with PBL, which were clearly positive.

Implication for Teaching

The results from the qualitative interviews have shown that students had an improved view of chemistry, chemists, and their roles in society. It's likely that the students realized the usefulness of chemistry, chemists, and chemists roles in the society. They also understood the challenges that chemists encounter as they perform their activities. Therefore, instructors must design their instruction to challenge the students and increase awareness of the relevance of the instructional activities to the real world.

This is important because it has a potential to raise students' awareness of the importance of chemistry and hence improve the likelihood of becoming chemistry majors.

What are the Students' Views of the PBL Environment?

The third assertion for this study is that 'students had views of the PBL instructional strategy as expected of PBL environments.' Descriptive and inferential statistics were used to present data to confirm this assertion. This section presents a discussion of this assertion starting with the influence of the confounding variables, quantitative, and qualitative data.

Confounding factors, including students' ACT scores, GPA, major, number of chemistry courses, and instructor, that we tested did not affect students' views of the PBL environment. This shows that students with varying characteristics had similar positive views of the PBL environment. Our data indicated that most students had a positive view of the PBL environment. In CHEM 1 72.1% and in CHEM 2 64.5% of students had mean PBLEI scores of 4 or greater. Only 3.5 and 1.1% of students had PBLEI scores of less than 3.0 in CHEM 1 and CHEM 2, respectively. This indicates that students had a positive view about most of the items on the PBLEI, suggesting that they enjoyed the PBL instructional environment. In terms of individual sections, student interaction and collaboration (SIC) was rated highly, followed by student responsibility (SR), and then Teacher support (TS). Quality of the problem had the lowest rating. PBL is one of the instructional approaches that advocates for cooperation amongst students and making students responsible for their own learning (Dochy et al. 2005). It is, therefore, not suprising that the students were satisfied with their interactions and their role in the learning process. This validates the aim of PBL of promoting students' as "active learners, who show independent study behaviour and responsibility for their own learning process" (Dochy et al., 2005, p. 60). This is encouraging because learners who are actively involved in the learning process are able to actively process information, activate prior knowledge, and build new knowledge upon it in a meaningful context (Dochy et al., 2005; Charlin, Mann, & Hansen, 1998). This is in line with the characteristic of PBL that encourages activities to support the learner in developing ownership for the overall problem or task

It has been observed that during both semesters, students consistently scored quality of the problem (QP) and teacher support (TS) lower than the other two variables, which was also observed by Dochy et al. (2005). It is likely that these students did not understand the aim of PBL. Students might have expected the instructor to be more involved in the learning process as is the case with direct instruction. For instance, whenever students faced challenges in PBL, the instructor did not provide a clear solution to the challenge, but asked appropriate questions to guide students in finding their own solution (Hmelo-Silver, 2004). This may not be recieved well by students who are used to direct instruction. Nevertheless, both TS and QP had mean scores greater than 3.7, indicating positive views of their instructor and quality of the problem.

The correlation analysis of the PBLEI for both semesters showed that all the PBLEI variables were significantly correlated to each other. This indicates that there is a positive relationship amongst all the sections of the PBLEI. This information is confirmed by the results of the regression analysis of the PBLEI sections. The beta (β) values from the regression model in CHEM 1 showed that only students' views of their responsibility (SR) contributed significantly to teacher support (TS), student interaction and cooperation (SIC), and quality of the problem (QP). However, all the other three predictors contributed significantly to student views of their responsibility (SR). A similar observation was found in CHEM 2, however in this semester, there was a small but significant contribution from quality of the problem (QP) to teacher support (TS) and viceversa. This shows that how students viewed their responsibility in the learning process will affect their views about the quality of the problem, teacher support, and student interactions and cooperation. It is not clear, however, how teacher support and quality of the problem contribute to each others' mean scores because of the mixed results observed between CHEM 1 and CHEM 2.

The qualitative results below corroborate the findings in the quantitative section. The students had views expected of the PBL environment as expressed through the interview results (Dochy et al, 2005). Constructivist teaching approaches require educational programs to be able to design the learning environment to support and challenge the learner's thinking (Savery & Duffy, 2001). Students interviewed in this study felt that PBL improved their ability to reason. Therefore, by acknowledging the role of PBL in their ability to reason, the students have shown that the instruction was in line with the tenets of constructivism. According to Gallagher (1995), teachers in PBL assume a new role of metacognition coaches instead of being didactic instructors. The teachers guide students through the process of inquiry through questioning, research of the activities, and synthesis of data. This increases students' awareness of their ability to think through a problem and select appropriate alternatives. Furthermore, according to Facione (1990, 2006), the specific process of critical thinking is comprised of the following steps:

(i) Analysis = identifying and examining ideas and arguments.

(ii) Inference = drawing conclusions.

(iii) Interpretation = clarifying meaning through categorization and translation.

(iv) Self-regulation = self-assessment and reflection.

(v) Explanation = justifying results, arguments or procedures.

(vi) Evaluation = assessing arguments.

Critical thinking is developed through the interactions that occur in the PBL environment. As a constructist learning environment, PBL instructors are encouraged to design the task and the learning environment to reflect the complexity of the environment students should be able to function in at the end of learning (Savery and Duffy, 2001). Furthermore, the learning environment must be able to support and challenge the learners' thinking. In this case, as students undergo the process of problem solving within their groups, they critically consider alternative solutions to choose the best (O'Grady and Alwis, 2002; Wee, 2004). In addition, when the facilitators ask probing questions during the process of problem solving, students' metacognition improves while making decisions (Masek & Yamin, 2011; Wee, 2004). In summary, problem solving encourages a "systematic cognitive process that promotes the development of the students' reasoning ability" (Masek & Yamin, 2011, p. 217). Furthermore, interactions that occur within the PBL environment such as discussions, debating, and sharing among others provide a conducive environment for critical thinking to occur (Masek & Yamin, 2011; Schmidt, 1993; Wee, 2004). Other authors (Tiwari et al., 2006; Yuan et al. 2008) also found that PBL improved students' critical thinking.

Students also felt that PBL improved their enthusiasm. Shen (2003) believes that the problems that students solve in the PBL environment help the students to use their intellect and collaborate with others. According to Shen (2003), this both broadens the scope of the students' minds and stimulates their enthusiasm. According to Hmelo-Silver (2004), one of the goals of PBL is to improve students' intrinsic motivation. Specifically, this motivation occurs when students work on problems that have relevance in their lives. Students who realize that the knowledge they get from the PBL activity can be applied to their immediate environment are more motivated to work on that problem. In this case, both problems in our PBL units had direct relationships to the current conversations about energy and food. Therefore, it was not surprising that the students were enthusiastic about the PBL environment.

Similarly, students felt that the PBL environment enhanced their independence in the learning process. One aim of constructivism is to give the learner ownership of the process used to develop a solution (Savery & Duffy, 2001). Therefore, it is satisfying to observe that that students acknowledged the importance of working independently. Gallagher (1995) believes that this occurs because teachers are able to model the art of problem solving for their students. Taking the role of a problem solver enhances students' feelings of independence in the learning process. In this case, students "can become truly self-directed and independent learners, empowered to approach the kinds of problems they will face as professionals" (Gallagher, 1995, p. 138). Results from this study reinforce findings by Ferreira and Trudel (2002), who found that students were excited about the autonomy that PBL provided. Furthermore, PBL encourages "self-directed learning, active engagement, and generalization, multiplicity of ideas, reflectivity, personal relevance, and collaboration" (Chin & Chia, 2006, p. 64). These attributes, combined with solving ill-structured problems, prepare students for real world challenges (Chin and Chia, 2006). In the PBL strategy, students usually become active, independent, and take more responsibility for their own learning. In their study, Gabr and Mohamed (2011) concluded that PBL had clear benefits in that it increased self-directed learning and problem solving skills of their study group. Therefore, the qualitative results from this study confirmed findings from other published research.

The students also enjoyed PBL because it involved solving real world problems. In fact, one of the core aims of PBL is to help teach students' skills that may help them solve real world problems (Hmelo-Silver, 2004). Furthermore, constructivist approaches encourage teaching strategies that support authentic learning environments (Savery & Duffy, 2001). Solving real world problems enhances the authenticity of the learning environment. Therefore, it was satisfying that students in this study felt that getting an opportunity to solve real world problems was one reason they liked PBL. The PBL activities guided students through the problem solving process that involved identifying a problem, creating research questions, designing a study, conducting research, and other steps involved in problem solving. Therefore, it's only fair that our students were able to recognize these processes as a strength of the PBL instructional strategy. Obviously, students were able to relate the problems that were addressed in the two PBL units that we used in our study to the current conversation. For instance, the conversations about organic foods and developing alternative energy sources are growing discussions in the US. The PBL activities are directly related to this conversation, and so, students could easily see the relevance of these two lab units.

Implication for Teaching

Results from this study have shown that students' had a positive view of the PBL environment. Students' interest is vital for effective learning to occur (Wilson & Peterson, 2006). According to Wilson and Peterson (2006), sometimes there is a disconnect between what instructors teach and what the learners learn. They argue that learning depends on several factors, including the learning environment and the interest of the student. Increased interest in the learning environment is likely to increase students' propensity to work hard as a result of increased enthusiasm. Instructors must therefore recognize this potential outcome from PBL when deciding which instructional strategies to use in their teaching endeavors. This study has showed that all the sections of the PBLEI correlated, indicating that PBL instruction must be approached holistically. The quality of the problem, teacher support, students' interaction and collaboration, and students' responsibilities must all be optimized to maximize the benefits from the PBL environment.

Relationships amongst Chemistry Students' Views, SEBs, and Attitudes?

The fourth assertion for this study is that '*there is a positive relationship amongst attitudes, SEBs, and students' views of the PBL environment.*' The data in response to this assertion are obtained from correlation and regression studies described below.

Medium and significant correlation coefficients were observed between attitudes, SEBs, and PBLEI scores in both CHEM 1 and CHEM 2. CHEM 1 pre-test correlation coefficient between attitudes and SEBs was 0.352 ($p = 0.001$). Further, the post-test attitudes scores had a significant correlation with SEBs ($r = 0.424$, $p = 0.001$) and PBLEI (r = 0.248, p = 0.023). Similarly, SEBs scores had a significant correlation with PBLEI (r = 0.327, p = 0.003). CHEM 2 pre-test correlation coefficients between attitudes and SEBs were 0.351 (p = 0.001). The post-test attitudes scores also had a significant correlation with SEBs (r = 0.351, p = 0.001) and PBLEI scores (r = 0.258, p = 0.015). Similarly, SEBs scores had a significant correlation with PBLEI scores (r = 0.288, p = 0.007). In both semesters, the observed correlation coefficients indicate the highest correlation between SEBs and attitudes, followed by SEBs and PBLEI scores, and then attitudes and PBLEI. This indicates a higher relationship between attitudes and SEBs than SEBs and PBLEI or attitudes and PBLEI. The coefficient of determinations (r^2) for the CHEM 1 and CHEM 2 pre-tests are 0.12, indicating that changes in attitudes scores explain 12 percent of change in the SEBs scores and viceversa.

Regression analysis indicated that the relationship between attitudes, SEBs, and PBLEI scores in both semesters conformed to a linear model. When attitudes were the dependent variable, the adjusted R^2 was 0.17, indicating that 17 percent of changes in attitudes scores could be explained by the combined changes in SEBs and PBLEI scores. Similarly, for SEBs scores as a dependent variable, the adjusted R^2 was 0.21 (F = 12.11), indicating that 21 percent of SEBs scores were explained by the combined changes in attitudes and PBLEI scores. The lowest R^2 (0.12, F = 5.54) was observed when PBLEI was made a dependent variable. In this case, 12 percent of changes in PBLEI scores were explained by the combined changes in SEBs and attitudes scores. The beta coefficients from the regression models showed that attitudes scores contributed more to SEBs scores (β = 0.366, p = 0.001) than PBLEI scores (β = 0.236, p = 0.022). However, both constructs contributed significantly to the SEBs scores. This shows that having better attitudes towards chemistry and a positive view of the PBL environment are both important in the changes observed in the SEBs. Similarly, SEBs scores contributed more to the attitudes scores ($\beta = 0.384$, $p = 0.001$) than PBLEI scores ($\beta = 0.123$, $p = 0.251$). In this case, a significant contribution was observed from SEBs only. These results corroborate with the finding that the calculated correlation coefficients clearly show a higher correlation between SEBs and attitudes. This also indicates that students' SEBs were more important in the changes in student attitudes toward chemistry, however, the students' view about the PBL environment did not translate into having a better view of chemistry and chemists in general. The PBLEI model also indicated a significant contribution from SEBs ($\beta = 0.270$, $p = 0.022$) and a nonsignificant contribution from attitudes ($\beta = 0.134$, $p = 0.251$), showing that higher self-efficacy beliefs will likely be related to having a more positive view of the PBL environment.

Similarly, the correlation coefficients between CHEM 2 attitudes and SEBs for pre- ($r = 0.351$, $p = 0.001$) and post-tests ($r = 0.333$, $p = 0.001$) were significant and had moderate effect sizes, indicating that as attitudes improved, SEBs also improved. The coefficients of determinations for CHEM 2 pre- and post-tests were 0.12 and 0.11, respectively, indicating that 12 and 11 percent of the variation in scores was predicted by interactions between attitudes and SEBs scores. This shows that there is a predictive relationship between students' chemistry SEBs and attitudes toward chemistry. In other words, efforts to improve students' SEBs may also improve their attitudes. A similar correlation result was observed by Li (2012) on students doing research methods and statistics and Yalcin (2005) on students doing computer and internet studies. Similarly, Nicolaidou and Philippou (2003) found a significant correlation between attitudes toward and SEBs in mathematics. Further, Nicolaidou and Philippou (2003) found that the interaction of attitudes and SEBs had a positive influence on student performace. Therefore, instructors should strive to instill postive attitudes and SEBs as a way to improve students' performance.

Implications for Teaching

Our results have also shown that there are significant correlations amongst attitudes, SEBs, and the students' view of the PBL environment. This shows that an improvement in one leads to the improvement of the others. This indicates that instructional strategies that maximize improvement in one of these factors may have an impact on the other two in the long run. In this case, students improved their SEBs and had a better view of the PBL environment. No improvement was observed on the quantitative attitudes data, however, the significance of correlation between attitudes and SEBs and attitudes and the students' view of the PBL indicate that PBL may have the potential to improve students' attitudes over time. Lastly, the problems that the students identified in the implementation of PBL may help future instructors who might want to use PBL to reflect upon what improvements to make for a better experience.

Limitations

Limitations that may affect this study include:

1. Students' lack of familiarity with PBL may affect the results. This is a limitation because PBL is one of the most student centered teaching strategies where students are given a big role in their own learning. This transfer of roles may need more time to settle into the students' learning styles. This problem was minimized by introducing students to

active instruction to familiarize them with active participation at the beginning of the semester. This ensured a smooth transition to PBL instruction.

2. The limitation inherent in the pre-post-test one group design is lack of a control group. This may raise doubt as to the actual influence of the PBL activities. However, paired pre- and post-test designs are used to measure changes in stable behavior such as attitude (Borg and Gall, 1983). Furthermore, paired sample t-test design has an advantage in that individual differences that occur between subjects are eliminated thereby increasing the power of the test (Beaumont, 2012).

Implications for Further Study

This study suggests the need to determine how effective PBL is compared to other instructional methods in changing students' SEBs. This will require a pre-/post-test control group design. In terms of attitudes toward chemistry, this study should be replicated, however, with a longer duration of the PBL experiences because attitudes are static and may need more time to observe a change. The cognitive aspect of the PBL environment has also not been exhausted in chemistry. More research needs to be done to fully comprehend the influence of PBL on problem solving and critical thinking in chemistry. There is also very sparse information on the implementation and outcomes of problem based learning chemistry courses other than general chemistry (Ram, 1999). There is need to explore in these chemistry courses how PBL influences the students' metacognition, critical thinking, and problem solving ability. Further research also needs to be done on instructors, especially how PBL influences their understanding and application of scientific inquiry in their classrooms and their roles in students' learning.

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Appendix A: Survey Recruitment Script

SCRIPT FOR ASKING SUBJECTS' PERMISSION TO USE THEIR SURVEY SCORES FOR RESEARCH PURPOSES (This will be used just before the pre-test): This script is based on the consent form.

As you might already be aware, I am conducting a research project entitled "Effect of implementing PBL in general chemistry laboratory." I would like to investigate how you feel about chemistry and the PBL environment. I would like your permission to use your pre/post test scores fom the CAEQ survey and your post-test scores from the PBLEI survey.

The consent form will be distributed with the CAEQ. To give your permission, you just need to sign the consent form on the space under surveys and drop your signed or unsigned consent forms in the box labeled CONSENT FORMS. The information collected during this project is confidential and, hence, your names or any other identifiers will not be used in any analysis or in any reporting of the research.

You may decide not to participate, or you can contact the Principal Investigator, Dr. M. Grunert by phone at (269) 387-2859 or by email at megan.grunert@wmich.edu if you change your mind and for any questions. There will be no prejudice or penalty for any decision you make regarding participation.

Thank you.

Appendix B: Interview Recruitment Script

SCRIPT FOR RECRUITING STUDENT SUBJECTS TO PARTICIPATE IN THE INTERVIEW (This will be used when giving participants the post-test): This script is based on the consent form.

As you might already be aware, I am conducting a research project entitled "Effect of implementing PBL in general chemistry laboratory." I would like to investigate how you feel about the PBL instruction. I, hence, invite you to participate in the interviews.

During this interview you will answer 7 questions on how you feel about the PBL units. The duration of the interview will be approximately 20 minutes. These interviews will be administered in the Mallinson Institute for Science Education library and will be audio-recorded.

You will not be identified to course instructors.

If you decide to participate in the interview you may sign the consent form on the space under INTERVIEWS on the consent form. You should attach signed or unsigned consent forms to your questionnaire responses and submit them next week.

You may decide not to participate, or you can contact the Principal Investigator, Dr. M. Grunert by phone at (269) 387-2859 or by email at megan.grunert@wmich.edu if you change your mind and for any questions. There will be no prejudice or penalty for any decision you make regarding participation.

Thank you.

Appendix C: Interview Email

EMAIL INFORMING SUBJECTS ABOUT INTERVIEWS

Dear (participant name),

As you are already aware, we are conducting a study to determine the effects of implementing PBL in general chemistry laboratory. As someone who signed the consent form for interviews, I would like to inform you that you have been selected to participate in the interview process. Your interview will take place in room (room number) on (date) at (time).

During this interview you will answer questions about your experiences with the PBL units. The duration of the interview will be approximately (20 minutes for student interview/45 to 60 minutes for TA interviews). These interviews will be administered in the Mallinson Institute for Science Education library and will be audio-recorded.

You will not be identified to course instructors.

You may decide not to participate, or you can contact the Principal Investigator, Dr. M. Grunert by phone at (269) 387-2859 or by email at megan.grunert@wmich.edu if you change your mind and for any questions. There will be no prejudice or penalty for any decision you make regarding participation.

Thank you.

Appendix D: Before Interview Script

SCRIPT FOR THE STUDENT INTERVIEW (This is to be used at the site of the interview before the interview begins.)**:** It is based on the consent form.

Thank you for participating in this interview. As you might already be aware, I invite you respond to the interview questions for the project entitled "The influence of PBL laboratory on chemistry students' attitude and self efficacy." I would like to investigate how you feel about the PBL instruction.

During this interview you will answer 7 questions on how you feel about the PBL labs. The duration of the interview will be approximately 20 minutes. All the information collected from this interview will be confidential; your name or other identifying features will not be used during the analysis and reporting of the research work. The transcripts will be locked for at least three years in Dr. M. Grunert's (principal investigator) cabinet. These transcripts will be coded so that your responses are not associated with you.

You are participating in this research voluntarily. You may decide not to participate, not answer certain questions or to contact me if you change your mind about participating or may quit at any time during the study. There will be no prejudice or penalty for any decision you make regarding participation. If you have any questions regarding this study you are free to email or call the Principal Investigator, Dr. M. Grunert. Her email address is megan.grunert@wmich.edu and phone number is (269) 387-2859.

Thank you.

Appendix E: Interview Questions

Student Interview Protocol:

My name is Lloyd Mataka from Mallinson Institute for Science Education. As you are already aware, this semester you have used problem based learning in sensors/biodiesel unit of CHEM 1110/CHEM 1130. To be able to implement this approach properly, we need to determine its strengths and weaknesses. Therefore, the aim of this interview is to get a clear picture of how you feel about the PBL approach.

The information you provide in this interview may be used to help develop a more appropriate PBL course. It may also be used for publishing in professional research journals and presented at conferences. However, your name or any other identifying information will not be used during analysis and publication of this information.

This interview has questions that focus on your perceptions about the problem based approach as an instructional method for general chemistry labs. Any time you feel that you are not comfortable, please do not hesitate to inform me.

PBL interview questions.

1. What was your experience with the Problem Based Learning lab unit (labs where you solved a problem)?
2. How did your experience with PBL compare to your experience with non-PBL labs?
3. What did you learn from PBL? What did you learn from the regular labs?

   Prompts (problem solving, applications from real life)

   Think about specific skills such as

   - Skills handling equipment.
   - Skills posing relevant questions.

- What about the real world applications?

4. What did you like about the regular labs? What did you like about the PBL labs?
5. What was challenging about the PBL labs?
6. How did the PBL affect your views about
    - Chemistry and its roles in society?
    - Chemists and their roles in society?
7. How did the PBL unit affect your ability to plan and conduct experiments?
8. How did the PBL unit affect your interest and/or confidence in participating or conducting undergraduate research?
9. How did the PBL unit affect your interest and/or confidence in enrolling in future chemistry courses?
10. What suggestions do you have for improving the PBL labs?
11. What advice do you have forwould you give to other students enrolled in the PBL labs?
12. Do you feel more or less confident about your abilities in chemistry as a result of completing the PBL laboratory unit? Why?
13. Are you more or less interested in chemistry as a result of completing the PBL laboratory unit? Why?
14. How has your attitude towards chemistry changed as a result of completing the PBL laboratory unit? What made your attitude change?
15. Would you be interested in participating in more PBL experiences? How likely are you to seek out other PBL experiences?

Appendix F: HSIRB Approval Letter

WESTERN MICHIGAN UNIVERSITY

Human Subjects Institutional Review Board

Date: February 21, 2012

To: Megan Grunert, Principal Investigator
Lloyd Mataka, Student Investigator
Kelley Becker, Student Investigator

From: Amy Naugle, Ph.D., Chair

Re: HSIRB Project Number 12-02-33

This letter will serve as confirmation that your research project titled "Effect of Implementing PBL in General Chemistry Laboratory" has been **approved** under the **exempt** category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: February 21, 2013

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