8-1-2015

Engineering the Path to Higher-Order Thinking in Elementary Education: A Problem-Based Learning Approach for STEM Integration

Abeera P. Rehmat
University of Nevada, Las Vegas

ENGINEERING THE PATH TO HIGHER-ORDER THINKING IN ELEMENTARY EDUCATION: A PROBLEM-BASED LEARNING APPROACH FOR STEM INTEGRATION

by

Abeera Parvaiz Rehmat

Bachelor of Science - Computer Science
St. John's University
2001

Master of Science - Elementary Education
Nova Southeastern University
2008

A dissertation submitted in partial fulfillment
of the requirements for the

Doctor of Philosophy - Curriculum and Instruction

Department of Teaching and Learning
College of Education
The Graduate College

University of Nevada, Las Vegas
August 2015

UNLV | GRADUATE COLLEGE

Dissertation Approval

The Graduate College
The University of Nevada, Las Vegas

July 23, 2015

This dissertation prepared by

Abeera P. Rehmat

entitled

Engineering the Path to Higher-Order Thinking in Elementary Education: A Problem-Based Learning Approach to STEM Integration

is approved in partial fulfillment of the requirements for the degree of

Doctor of Philosophy – Curriculum and Instruction
Department of Teaching and Learning

Hasan Deniz, Ph.D.
Examination Committee Co-Chair

Kendall Hartley, Ph.D.
Examination Committee Co-Chair

Danielle B. Brown, Ph.D.
Examination Committee Member

Brendan O'Toole, Ph.D.
Graduate College Faculty Representative

Kathryn Hausbeck Korgan, Ph.D.
Graduate College Interim Dean

ABSTRACT

Engineering the Path to Higher-Order Thinking in Elementary Education: A Problem-Based Learning Approach to STEM Integration

by

Abeera Parvaiz Rehmat

Dr. Hasan Deniz, Examination Committee Co-Chair
Dr. Kendall Hartley, Examination Committee Co-Chair
Department of Teaching and Learning
University of Nevada, Las Vegas

As we progress into the 21st century, higher-order thinking skills and achievement in science and math are essential to meet the educational requirement of STEM careers. Educators need to think of innovative ways to engage and prepare students for current and future challenges while cultivating an interest among students in STEM disciplines. An instructional pedagogy that can capture students' attention, support interdisciplinary STEM practices, and foster higher-order thinking skills is problem-based learning. Problem-based learning embedded in the social constructivist view of teaching and learning (Savery & Duffy, 1995) promotes self-regulated learning that is enhanced through exploration, cooperative social activity, and discourse (Fosnot, 1996).

This quasi-experimental mixed methods study was conducted with 98 fourth grade students. The study utilized STEM content assessments, a standardized critical thinking test, STEM attitude survey, PBL questionnaire, and field notes from classroom observations to investigate the impact of problem-based learning on students' content knowledge, critical thinking, and their attitude towards STEM. Subsequently, it explored students' experiences of STEM integration in a PBL environment. The quantitative results revealed a significant difference between groups in regards to their content knowledge, critical thinking skills, and STEM attitude. From the qualitative results, three themes emerged: *learning approaches*, *increased interaction*, and *design and engineering implementation*. From the overall data set, students described the PBL environment to be highly interactive that prompted them to employ multiple approaches, including design and engineering to solve the problem.

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to all of those individuals who have contributed to my success.

To my committee co-chairs, Dr. Hasan Deniz and Dr. Kendall Hartley, for their encouragement and support. Words cannot express my appreciation for all they have done to help me navigate through this difficult process. Dr. Danielle B. Brown and Dr. Brendan O'Toole, my committee members, for agreeing to serve on my committee and for their input during this research study. Finally, a special thank you to my former committee members, Dr. Kent J. Crippen, for accepting me in this degrees program and his continued support and Dr. Janelle M. Bailey who believed in me and gave me the confidence and knowledge on which I continue to draw on today.

A special appreciation goes out to my family. To my deceased father, who kindled my love for learning and taught me to never give up. I wish he was here to witness this moment. My mother, for her endless support and patience, without her presence this would not have been possible. I am also grateful to my brother, Zohaib Rehmat, for pushing me to pursue my dreams. More importantly, his encouragement, time and his insights have been critical to this dissertation. I am very grateful to my son, Eisa, for his patience and understanding throughout my doctoral journey. He inspired me with his engineering ideas and creativity, which helped motivate me to progress awareness and understanding of STEM at the elementary level.

My appreciation also goes out to my dear friend and research companion Marissa C. Owens. She was always there to listen to my crazy ideas and helped me perfect them. Her friendship, positivity, and support have been instrumental in this long journey.

Special recognition goes to the Principal of the participating school, Dr. Carrie Buck, and the participating teacher, Amandalynn Lemon. They both allowed me to collect data in their facility/classroom to advance my research. Finally, to all the wonderful fourth grade students who were involved in this study. This research would not have been possible without their involvement.

DEDICATION

"Education is not the learning of facts, but the training of the mind to think."

– Albert Einstein

This work is dedicated to my son Eisa, who is the brightest light in my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Education has significantly evolved over the course of history. In recent years Science, Technology, Engineering, and Mathematics referred to as STEM education, has become a critical component in modern educational trends (Becker & Park, 2011; Kuenzi, 2008). This is in part due to a decline in the number of undergraduate degrees earned in STEM content fields since the year 2000 (Kuenzi, 2008). The United States has been impacted by the regression in STEM knowledge as it is losing ground in the global market. For the U.S. to contend and become a force in the current global economy, it is vital to implement programs that develop a workforce with STEM content knowledge.

In an effort to address the current status of STEM education in the nation, initiatives that focus on STEM integration have become progressively prevalent in K-12 education. This support for interdisciplinary curricula can be seen in the new *Common Core Standards* for language arts and mathematics (National Governors Association, 2010) and the *Next Generation Science Standards* (Achieve, Inc., 2013). Additionally, engineering practices and technology are also permeated into the Next Generation Science Standards (Achieve, Inc., 2013) to further increase comprehension in these areas (English, Hudson, & Dawes, 2013). This amalgamation of core content areas along with science and engineering practices in the Next Generation Science Standard is believed to have the potential to provide students with the knowledge and skills they need to become successful well-informed individuals (English et al., 2013; Sanders, 2009). Nevertheless, the curricula alone will not do justice to STEM. As a result, major emphasis is being placed on research to consider STEM integrated curricula and pedagogies since they have the potential to support student learning, nurture interest in STEM disciplines, and prepare them for future careers (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Fortus, Krajcikb, Dershimer, Marx, & Mamlo-Naaman, 2012; Mehalik, Doppelt, & Schunn, 2008). While there is no clear consensus on which is more effective, many studies have pointed towards an active approach for science teaching and learning rather than a passive approach (Amador & Gorres, 2004; Hmelo-Silver, 2004, Savery & Duffy, 1995). Concurring with this view, constructivist approaches to teaching and learning are considered to be student centered in which learners are actively engaged and deep understanding of concepts is fostered.

Problem-based learning rooted in a social constructivist view of learning contends that knowledge is socially constructed and mediated by language and interaction under the guidance of a facilitator (Vygotsky, 1978; Zhang, Parker, Eberhardt, & Passalacqua, 2011). Problem-based learning can support STEM integration by providing students with rich interdisciplinary learning experiences that can enrich content knowledge plus cultivate higher-order thinking skills. Problem-based learning can also develop collaborative skills and encourage independency while motivating students to become lifelong learners (Hmelo-Silver, 2004). Savery and Duffy (1995), state that problem-based learning (PBL) is an exemplar of social constructivist learning environment. Problem-based learning instructional method uses real world problems to activate students' prior knowledge, which helps them to make concrete connections to real world situations (Lambros, 2002; Goodnough, 2006). The ability to conduct in-depth investigations through problem-based learning provides students an opportunity to pursue their individual interest and find solutions to problems in the best way they see fit.

Barrows (2000), describes problem-based learning as a total approach to education, one that has the potential to replace traditional lecture based approach to promote students' conceptual knowledge and higher order thinking skills. Thus, it would be in the best interest of education to encourage educators to utilize problem-based learning instructional method to tackle this STEM dilemma. Interdisciplinary STEM problems taught using problem-based learning can ignite creativity and interest among students as well as develop higher-order thinking skills, communication skills, and strengthen their understanding of STEM content areas.

Definition of Terms

This dissertation study has used the following terms and definitions. To fully understand these commonly used terms, definitions are provided below.

Attitude – Is defined as "feelings, beliefs, and values held about an object that may be the enterprise of science, school science, the impact of science on society or scientists themselves" (Osborne, 2003, p. 1053).

Critical Thinking Skills – There are several definitions of the term critical thinking; the most commonly used definition is "purposeful, self-regulatory judgment that results in interpretation, analysis, evaluation, and inference as well as explanation of the evidential, conceptual, methodological, or contextual considerations upon which that judgment is based" (Facione, 1990, p. 2).

Problem-based learning (PBL) - An "instructional method in which students learn through facilitated problem solving" (Hmelo-Silver, 2004, p. 235). The problem is a pivotal starting point of PBL, which "creates learning through both new experience and the reinforcement of existing knowledge" (Lambros, 2002, p. 1).

Social Constructivism – A branch of constructivism that has derived from Vygotsky's socio-cultural theory (1978) that "emphasizes the importance of culture and language based social interactions and knowledge at a group level" Seimears, Graves, Schroyer, & Staver, 2012, p. 268).

STEM - For the purpose of this dissertation study, STEM is an acronym for science, technology, engineering, and mathematics. STEM integration combines the "four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections among these disciplines and real-world problems" (Moore & Smith, 2014, p. 5).

Traditional Learning – For the purpose of this dissertation study, traditional learning is a teacher-centered approach where the teacher is the focus of the learning environment. In such an environment, teaching is assented with the "belief that teaching students the theories and principles is the most direct and efficient way for them to gain the fundamental conceptual knowledge of the topic under study (Hung, 2013, p. 29).

Purpose of the Study

A strong foundation in basic skills and content areas can help propel the development of 21st century skills and behaviors that can prepare students to become independent thinkers, problem solvers, communicators, and decision makers (Silvia, 2009). These skills are not new, rather essential and now required in the workplace. The application of constructivist pedagogies, such as problem-based learning, in the classroom can foster the development of such skills while preparing students for the future. Problem-based learning encourages students to think like experts and behave like professionals to solve real-world problems as they gain understanding and develop these imperative skills.

The effectiveness of problem-based learning for teaching and learning has been explored in numerous studies (Araz & Sungur, 2007; Tarhan, Ayer-Kayali, Urek, & Acar, 2008; Wong & Day, 2009; Zhang et al., 2011). The benefits of learning through an assimilated curriculum in K-12 education have also been examined (Barker & Ansorge, 2007; Inceoglu, 2010; Mehalik et al, 2008). Nonetheless, there is a lack of research in using problem-based learning as a framework for integrated STEM education (Asghar, et al., 2012) mainly at the elementary level (English et al., 2013; Weiman, 2012). Also, further examination on *if* and *how* problem-based learning improves critical thinking skills in a K-12 environment is desired (Azer, 2009; Forrester, 2004; Sendag˘ & Odabas, 2009; Simons et al., 2004). In order to see a greater impact on students' STEM learning, implementation must begin at the elementary level (Murphy & Mancini-Samuelson, 2012). Considering this, further research is necessary to explore effective methods that promote changes in students' critical thinking skills, strength their content knowledge and understanding, and kindle their interest in STEM subject areas.

This dissertation research study investigates how an integrated STEM curriculum implemented in an elementary classroom through a problem-based learning instructional method compares to a STEM integrated curriculum implemented through a traditional learning instructional method. The students' STEM content knowledge, critical thinking skills, and attitudes towards STEM will be examined using a pre/post study design for both methods. In examining these effects, the study also investigates students' experiences and perceptions of the problem-based learning methodology.

Research Questions and Hypotheses

Research Questions

The following research questions and hypotheses will guide this dissertation study.

1. What is the impact of problem-based learning as compared to traditional learning on fourth grade students' STEM content knowledge?
2. What is the impact of problem-based learning as compared to traditional learning on fourth grade students' critical thinking skills?
3. What is the impact of problem-based learning as compared to traditional learning on fourth grade students' attitude towards STEM education?
4. How will students describe their STEM integrated problem-based learning experience after implementation?

Hypotheses

Problem-based learning is an all-inclusive hands-on/minds-on approach to comprehend the content being presented in the classroom. Considering the audience is elementary education students, the fourth grade students that participate in the problem-based learning group will show greater gains in STEM content knowledge assessment than fourth grade students that participate in traditional learning group.

As for the second research question, the fourth grade students that participate in the problem-based learning group will show greater gains in critical thinking skills than fourth grade students that participate in traditional learning group. This will be evident because problem-based learning will actively engage the students in the problem solving process and stir interest in the STEM content areas.

Finally, with regards to the third question, fourth grade students that are involved in the problem-based learning intervention will show positive gain in their attitudes towards STEM as compared to the traditional learning group. A positive attitude toward STEM will be guided by the integrated hands-on experience, which is uncommon in our classrooms today.

Methods

This study used a quasi-experimental mixed methods design to address the research questions. The sample size of 98 fourth grade elementary students served as this study's participants. Out of the four fourth grade classrooms, two classes were randomly assigned to the treatment group and the other two classes to the control group. The students in the treatment group engaged in STEM integrated units using problem-based learning methods while the control group engaged in lessons based on the same STEM curriculum, but through traditional learning methods. The participants in both groups completed the content knowledge assessments, the critical thinking test, and a STEM attitude survey. Additionally, the treatment group participants completed the problem-based learning questionnaire. Along with these assessment instruments, classroom observations were also conducted and field notes were taken.

Results

The results indicated that both groups' scores on the content knowledge assessment showed an improvement over time. However, with respect to groups, the treatment group performed significantly better on the content knowledge assessments than the comparison group.

The treatment group participants performed significantly better than the control group on the *Test of Critical Thinking*. The effect size for these changes was large displaying a practical significance. Thus, we can conclude that the improvement in the treatment group's critical thinking skills is led by problem-based learning methodology.

Although there are changes in the treatment and the control groups' attitude over time, there was a significant difference found between the treatment and control group regarding their attitude towards STEM. The treatment group displayed significantly more positive attitude regarding STEM as compared to the control group. These differences in the groups' attitude again can be attributed to the teaching methods.

The outcome from the qualitative data showed that participants in the treatment group enjoyed the problem-based learning experience. The participants indicated that problem-based learning encouraged them to apply various learning approaches and also allowed them to be socially interactive. Additionally, it incorporated design and engineering, which they found to be the highlight of the problem-based learning experience. Overall, the effectiveness of problem-based learning as an instructional method that can promote integrated STEM has been demonstrated in this study.

Organization

To further understand the research associated with problem-based learning, a review of literature on problem-based learning instructional method supported by social constructivist learning theory will be presented in Chapter 2. Chapter 3 will present the literature review in STEM education and potential benefits of assimilated STEM curriculum. The literature review is separated into two chapters for clarity, cohesion, and to provide an in-depth understanding of each area. In Chapter 4, the methodology of study is provided. This is followed by Chapter 5, in which analysis strategies and results of the study are discussed. Lastly, Chapter 6 of the dissertation will close with the discussion, educational implications, and limitations of this study. Future research to enhance this study will also be presented in Chapter 6.

CHAPTER 2

PROBLEM-BASED LEARNING

Definition of Problem-Based Learning

Problem-based learning (PBL) was originally introduced in the medical field during the late 1960's because of the concern that traditional education (lectures, rote memorization) acquired by medical students had little effect on their performance during residency (Ferreira & Trudel, 2012). However, over the years problem-based learning instructional method has been adopted by several disciplines across K-16 settings (Savery, 2006: Ravitz, 2009). Today, there is still a lack of consensus on a definition for problem-based learning as various methods have been employed to support teaching and learning (Hmelo-Silver, 2004; Jerzembek & Murphy, 2013; Schettino, 2012). Hmelo-Silver (2004) defines problem-based learning as an instructional approach in which students learn through facilitated problem solving. Savery (2006) describes problem-based learning as a learner-centered approach in which the learner is empowered to conduct research, assimilate theory and practice, while applying knowledge and skills to develop a viable solution to a defined problem. Schmidt's (1993) definition of problem-based learning emphasizes that students solve problems while a tutor facilitates their learning. While Schettino (2012) defines it as:

> An instructional approach of curriculum and pedagogy where student learning and content material are constructed through the use, facilitation, and experience of contextual problems in a de-compartmentalized, threaded topic format in a

discussion-based classroom setting where student voice, experience, and prior knowledge are valued. (p. 347)

Problem-based learning is a student-centered approach in which students acquire knowledge through collaboration and problem solving (Hmelo-Silver, 2004; Norman & Schmidt 2000). In a problem-based learning classroom the teacher takes the role of a facilitator that guides the students through the investigative process rather than serves as a leader (Liu, Wivagg, Geurtz, Lee & Chang, 2012). Gallagher, Stepien, Sher, and Workman (1995) identified three characteristics of problem-based learning: (1) introducing learning with a problem, (2) ill structured problems should be employed exclusively, and (3) the instructor is a facilitator of metacognition. Learning in problem-based learning does not initiate until the students have encountered an "ill-structured" problem, which is one that does not have all the necessary information to develop a solution (Chin & Chai, 2008). As Pepper (2010) further asserts, ill structured problems designed for problem-based learning represent authentic real world situations that do not necessarily have a single solution and can be interdisciplinary.

Although these problems are open-ended with varied solutions, they serve as the impetus for students to enhance their content knowledge as well as higher-order thinking skills (Barrows, 2000; Goodnough & Nolan, 2008; Hmelo-Silver, 2004). At the college or university level these problems are designed to mimic the professional world that students will dive into upon graduation (Pepper, 2010). According to Savin-Baden (2001) the flexibility and multiplicity of problem-based learning instructional methods allow them to be executed in a variety of ways in various subject areas. Greenwald (2000) claims, that problem-based learning provides a powerful means to conduct scientific inquiry. This promotes students active involvement in interpretation and understanding of new science content, while connecting this new knowledge to prior knowledge in meaningful ways.

Educational Psychology Theory for PBL

Constructivism is a theory of knowing and learning that argues that humans generate knowledge and meaning from interaction between their experiences and ideas (Fox, 2001; Walker & Lambert, 1995). The central principle of this approach is that learners can only make sense of new situations in terms of their existing understanding (Fosnot, 1996; Fox, 2001; Phillips, 1995). The constructivist view of teaching emphasizes student generated hypotheses and investigations (Alouf & Bentley, 2003). This view encourages students to contribute by generating their own ideas and pursuing their own investigations.

The constructivist view draws from a variety of fields including philosophy, psychology, and science (Walker & Lambert, 1995). Accordingly, constructivist ideas span across a wide-range of philosophical and theoretical spectrums. These ideas deviate into diverse psychological, epistemological, sociological, and historical directions (Phillips, 1995). Immanuel Kant was the first philosopher of constructivism in modern philosophy. He claimed that scientific knowledge is actively constructed from each scientist’s observational experience (Phillips, 1995). Other prominent twentieth century educators that have been linked to ideologies of constructivism include: Dewey, Piaget, and Vygotsky. Nearly all constructivists agree that knowledge is actively constructed and not passively received (Phillips, 1995). These constructions are influenced and supported by social factors that shape cognitive development (Haylock & Thangata, 2007). The social and cultural aspect of constructivism is fundamental to the values of social constructivism guided by Vygotsky.

Social Constructivism

Social constructivism is a branch of constructivist thought, which emphasizes that learning and development occurs in socially and culturally shaped context (Palincsar, 1998). The focal points of social constructivism are group and language (Staver, 1998). These social constructivist dogmas in most literature are attributed to Vygotsky who believed that knowledge is self-regulated adaptation by individual construction (Vygotsky, 1978). Vygotsky (1978) claimed that all individual construction is mediated by social factors and learning does not just take place within the individual. Thereby, the learning context is vital in shaping knowledge. Likewise, learning is an experience taking place within a learning environment in which students are active participants creating their own knowledge (Schreiber & Valle, 2013; Vygotsky, 1978). Vygotsky was the originator of the *sociocultural theory*, which has three essential components:

1. The learner develops as changes in social context impact cognition – termed *genetic or developmental method*
2. Cognition is socially and culturally mediated; mental process in the individual have their origin in social process
3. Cognitive development is mediated by cultural tool and symbolic language system (Vygotsky, 1978; Wertch, 1985).

For Vygotsky, development and learning were social aspects that were dependent upon signs and tools, particularly thinking and speech that mediated cognition and mental processes (Smagorinsky, 1995). He postulated that an individual's cognitive development could be traced back to their cultural frames of reference and their social activity. He further asserted that this development was enabled through language along with other psychological tools. Vygotsky (1978) stated that developmental movement in a child's thinking occurs from the social to the individual and not from the individual to state of socialization.

The sociocultural theory has been influential in education in explaining how cultural, social, and cognitive aspects impact learning and instruction. Vygotsky's zone of proximal development (ZPD) embedded in the sociocultural theory explains genetic development housed in an educational setting (Howe, 1996).

The zone of proximal development. The zone of proximal development (ZPD) explains how learning should be aligned with the child's development level (Palincsar, 1998). Vygotsky (1978) identifies the zone of proximal development as the "distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86). He claimed, that to understand the connection between learning and development, the distinction between the two development levels, the *actual* and *potential*, must be understood (Vygotsky, 1978). At the actual development level, a child can perform tasks independently while at the potential development level the child needs assistance to complete the task (Vygotsky, 1978). Moreover, learning takes place when a discussion on what they already know occurs among children in a social situation as well as when they construct knowledge and conjecture on what they are about to discover. Vygotsky (1978) further stressed that the zone of proximal development equips educators and psychologist with a tool that is used to understand the internal course of development in an individual. It promotes evaluation of students' performances while they are engaged in actual instructional activities in science education (Dixon-Krauss, 1996; Vygotsky, 1978).

Many commonalities and differences exist between the views of constructivists and social constructivists. Through Vygotsky's perspective, cognitive development is studied by investigating the processes partaken by an individual while engaged in shared endeavors and how this particular engagement impacts involvement in other activities. In contrast, Piaget envisioned perspective learning as controlled by development (Palincsar, 1998). The significance of both theories, Piaget's and Vygotsky's, is that they are applied to describe the cognitive processes involved in the construction of knowledge by individuals in science teaching and learning. As Howe (1996) noted, the main difference between Piaget and Vygotsky is their characterization of an individual's thought construction in science education. For Piaget, the driving force for scientific knowledge construction is internal guidance by an individual's maturation, while for Vygotsky this force of knowledge construction is external embedded in a social domain.

On the other hand, formal education for both Vygotsky and Dewey was imperative for child development and their ability to think. They also shared similar views about language including the role of the school and teacher in child development. Although both emphasized that instruction should begin at the child's appropriate developmental stage, Dewey viewed that without perplexity, growth could not occur and required a teacher's assistance to help the child reflect on past experiences before moving forward in inquiry with new experiences. While, for Vygotsky, the school was a flexible tool in which the social environment itself was the child's teacher. Thus, if the environment was controlled so was the learning. Hence, it is important for the teacher to create the environment in a meaningful and intentional way to influence student learning. These ideologies and their dimensions, cognitive and social, are central to our educational system. They have been utilized to define science education and have been applied to teaching and learning.

Problem-Based Learning and Social Constructivism

Social constructivism has been applied to teaching and learning in science education and has been considered a highly effective method for knowledge acquisition and instruction (Driver et al., 1994; Powell & Kalina, 2009). It promotes social interaction among students in the classroom, while allowing them to apply their critical thinking process in learning (Powell & Kalina, 2009; Watson, 2001). Schunk (1991) states that this shift from traditional model of teaching to a social constructivist model has changed the role of the learner as being an active and social contributor to the learning environment verses being a mere receiver of diffused knowledge. Furthermore, social interactions nurture genuine and valid discussions about an experience while encouraging ideas and perspectives to be examined, assessed, and transformed into meaningful understanding (Jadallah, 2000).

Problem-based learning stands within this philosophy of social constructivism, because of the many overlapping similarities between the characteristics of problem-based learning and Vygotsky's sociocultural theory (Li, 2012; Savery & Duffy, 1995). In problem-based learning, knowledge is attained through engagement by undertaking a complex problem (Savery, 2006). This process of exploration provides experiences for students and allows them to develop understanding as they make sense of the material content. The goal of the ill structured problem in problem-based learning is to stimulate dialogue and argumentation (Hmelo-Silver, 2004). According to the sociocultural theory, language and discourse is the most important process in a social constructivist classroom. As Bächtold (2013) confirms that the focus of sociocultural theory is language, which functions to enable communication between the learners and/or the teacher.

In problem-based learning, the learning environment is democratic and student centered, where the teacher is the facilitator (Hmelo-Silver, 2004). The facilitator is responsible for providing guidance through scaffolding, modeling, and questions. This scaffolding fades as the student becomes more confident and experienced with PBL (Hmelo-Silver, 2004; Li, 2012). Likewise, as in Vygotsky's sociocultural theory, the teacher or an advanced peer plays the same role; to provide guidance so the student can reach a new conceptual understanding. This guidance can also be provided through scaffolds (Hodson, 1999).

The many similarities discussed between the Vygotskian theory and problem-based learning clearly indicates that social constructivism is the underlying educational theory and framework for a problem-based learning pedagogy.

Implementation of Problem-Based Learning

The objective of problem-based learning approach is to provide students with real-world experiences and to help them develop lifelong learning skills (Hmelo-Silver, 2004). These skills identified by Barrow and Kelson (1995) include: (1) develop a broad knowledge base, (2) develop efficient problem solving skills, (3) become independent and lifelong learners, and (4) develop intrinsic motivation for learning.

In addition to problem-based learning having multiple definitions, there are also multiple ways of implementing problem-based learning into the classroom. Hmelo-Silver (2004) suggests three steps of problem-based learning cycle, which include: identifying the problem, self-guided investigation, and reporting. Gallagher et al. (1995) identified a five-step method of implementing problem-based learning to replicate science practices: (1) problem presentation, (2) analysis of problem (3) self-regulated learning, (4) data organization, and (5) solution presentation. While Delisle (1997) took this further and recommended a seven step approach: (1) creating a proper environment, (2) connecting with the problem, (3) creating a structure, (4) reviewing the problem, (5) revisiting the problem, (6) product creation, and (7) evaluation.

Goodnough and Cushion (2006) used a qualitative design to explore the difficulties faced by high school teachers during design and implementation of problem-based learning. They found that teachers had a difficult time creating a problem-based learning unit in terms of topic selection, determining the level of structure to be incorporated into the problem-based learning experience for students, and deciding on appropriate assessments. Most teachers struggled with determining how much feedback to provide through facilitation during execution. Also, classroom observations revealed that students liked learning through problem-based learning because it promoted active learning, made science relevant, provided variety in learning, and supported group work.

Additionally, effective implementation of problem-based learning requires various scaffolding techniques (Saye & Bush, 2002). Two types of scaffolds proposed by Saye and Bush (2002) are *soft scaffold* and *hard scaffolds*. Soft scaffolds are dynamic and a form of quick guidance provided by the teacher while diagnosing the learners' understanding. Hard scaffolds refer to static support, which can be foreseen and planned in advance based on typical difficulties faced by students on task. Scaffolding motivates students to be independent learners while developing higher order thinking skills, which can assist them to confront and tackle challenges on their own (Liu et al., 2012).

In a problem-based learning environment the effects of hard scaffolds in a middle school class was examined to see what role they play on students' learning. Simons and Klein (2007) discovered that students in the optional scaffolding and required scaffolding conditions performed significantly better than those in the no scaffolding condition. Students' achievement levels were significantly related to individual posttest scores; higher achieving students scored better than lower-achieving students on the posttest, while students' notebooks revealed that those in the required scaffolding condition produced more highly organized project notebooks containing a higher percentage of entries directly relevant to the problem. In this study, out of the five seventh grade classes that participated, two were assigned to the scaffolding required condition, two were assigned to the scaffolding optional condition, and one class was assigned to the no scaffolding condition (control group). In this study, the scaffolding was beneficial for student learning and had a positive impact on students' performance.

On the contrary, Choo, Rotgans, Yew, and Schmidt (2011) reported that there was no statistically significant difference between the levels of understanding between students with worksheets as scaffolding tools versus those with no worksheets. The questionnaire results indicated that in a problem-based learning environment the influential factor was the tutor, followed by team and class dynamics, while the influence of the worksheet was rated the lowest. The authors explored the effect of worksheets as a scaffolding tool on students' learning achievement in a problem-based learning environment enrolled in an immunology course in Singapore. The students were randomly divided into two experimental groups, one with worksheets and one without. Data sources included a recall test and a learning questionnaire. Although this study indicates that scaffolding did not benefit student learning; several other studies conducted have suggested that scaffolding can provide students with intellectual support by reducing cognitive load (Hmelo-Silver, 2004; Hmelo-Silver, Duncan & Chinn, 2007; Saye & Bush, Simons & Klein, 2007).

As noted, there is not a certain agreed upon process to incorporate problem-based learning for teaching (Delisle, 1997; Hmelo-Silver, 2004; Gallagher et al., 1995). However, the tools suggested along with guidance provided by a facilitator can be critical for successful implementation of problem-based learning.

Teacher's Role in a Problem-Based Learning Environment

Over the years, the population of our nation has dramatically increased leading to an influx of diversity in our classrooms. Our classrooms have not only become more diverse in terms of cultural backgrounds and ethnicity, yet increased in diversity with regards to individuality, such as personal strengths, weaknesses, and mental ability (Kalpana, 2014). In such an environment the role of a teacher is crucial to the learning process. Hodson (1999) assets that teacher has a significant role as per the Vygotskian theory, which is to lead students to new level of conceptual understanding. In a classroom the knowledge is not individually created, but rather a teacher is more involved in planning and managing the social interaction that fosters student inquiry and knowledge construction (Jadallah, 2000). Seimears, Graves, Schroyer, and Staver

(2012) points out that a teacher needs to use a variety of strategies to organize the information and concepts. These strategies include: (1) questioning, (2) examining, (3) engaging, (4) exploring, and (5) developing new insights. For students to efficiently learn and engage in the scientific process, the teacher should breakdown concepts for the student. Learning enhances and becomes more meaningful when students' prior knowledge along with experiences is utilized to create their personal frame of thought (Bevevino, Dengel, & Adams, 1999). Teachers that integrate such strategies in their instructional practices not only provide students with physical experiences, but also help them make personal sense of how knowledge claims are generated and validated (Driver et al., 1994). Nayor (1999) recommends that teachers capitalize on the understanding of the learner to help them use their experiences to learn. He further stresses, that teachers should use the learners' experiences to promote the development of active learning, while fostering the learners' independence.

In a case study conducted by Tytler, Waldrip, and Griffiths (2002), it was determined that the most effective factor in student achievement is the teacher. The teacher is the conductor of the class; therefore, to be effective with development of a large scale of improvement in teaching and learning of science, a clear vision of how the teacher operates in the classroom must be developed. In this case study, nineteen teachers from three different states were interviewed on their science teaching practices, beliefs, and commitments. These teachers were selected based on school recommendation or were former government curriculum advisors. The similarities that were apparent among the teachers was their use of constructivist practices, their commitment to student engagement, and their motivation to develop deeper levels of knowledge with understanding (Tytler et al., 2002). The researchers observed in all of the participating classrooms that children were stimulated to question, explore, while thinking critically. The study showed that they were comfortable in their setting and felt challenged along with receiving adequate support from the teacher.

Other elements that contributed to their effective teaching was their concern regarding the role of the community in learning, learning as a collaborative activity, plus the individual learning experience (Tytler et al., 2002). Each teacher saw learning as a socially interactive activity in which the students expressed their ideas, consequently, moving towards a shared understanding. The authors found that all these teachers viewed the learner as an active sense maker who engages with phenomena and ideas to construct knowledge. These educators applied effective instructional strategies to support the learning in their classroom (Tytler et al, 2002).

Comparably, a one-year case study in Taiwan was conducted in a fifth grade mathematics classroom to study students' and teachers' behavior patterns in a problem-based learning environment. Researcher (Li, 2012) reported that initially the students were engaged, participated, and collaborated during the study. Nevertheless, during the middle of the intervention their behavior changed. They became more disruptive as they were often found off task causing the teacher to become aggravated. Her frustration was not only due the class's disruptive behavior, but lead by her struggle to balance between teaching and facilitating. As she gained more confidence within herself, she realized that her role is not to directly instruct as a content expert, rather aid the learning and stimulate discussion with student engagement. This awareness enabled her to bring the class back on task towards the end of the intervention.

The presented studies signify the importance of an educator in a problem-based learning environment. These outcomes support the idea that a teacher's role under the social constructivist theory in conjunction with problem-based learning is imperative to the learning process. It is the learner and educator coupled with social interaction and discourse that provide meaningful learning that enhances students' experiences (Bevevino et al., 1999; Davis, Sumara, & Luce-Kapler, 2000; Driver et al., 1994; Hodson, 1999; Kalpana, 2014; Palincsar, 1998; Powell & Kalins, 2009). The learning occurred through these experiences can cultivate scientific knowledge with comprehension while improving students' higher-order thinking skills.

Effectiveness of Problem-Based Learning

PBL Research in Post-Secondary Education

Problem-based learning instructional methods have been applied in various disciplines. The majority of the empirical research in regards to effectiveness of problem-based learning has been directed in the medical field (Hmelo-Silver, 2004). Several comparative meta-analyses have been conducted to explore the benefits of problem-based learning (Albanese & Mitchell, 1993; Berkson, 1993; Colliver, 2000; Dochy, Segers, Van den Bossche, & Gijbels, 2003; Gijbels, Dochy, Van den Bossche, & Segers, 2005; Strobel & Barneveld, 2009; Vernon & Blake, 1993). Discoveries advocate that students engaged in problem-based learning do not perform adequately on factual knowledge of basic science, yet perform slightly better on clinical problem solving and clinical performance tests (Albanese & Mitchell, 1993; Vernon & Blake, 1993). Berkson (1993) concludes that a problem-based learning curricula graduate is not different from his or her counterpart in traditional curricula and that problem-based learning implementation can be demanding to both faculty and students. There are results that have been more positive indicating that problem-based learning is superior to traditional methods in several of the domains examined, such as long-term knowledge retention, formative assessments, and knowledge recall (Albanese & Mitchell, 1993; Colliver, 2000; Dochy et al., 2003; Gijbels et al., 2005; Strobel & Barneveld, 2009; Vernon & Blake, 1993).

Problem-based learning has also shown to increase students' critical thinking skills, problem-solving skills, achievement, and decision-making skills (Birgegard & Lindquist, 1998). According to Barell (2006) in the 21st century, skills such as critical thinking, problem solving, collaboration, and creativity are essential for all humankind. In Problem-based learning students' are accountable for their own learning, which obliges them to be reflective while applying their higher-order thinking skills (Hmelo-Silver, 2004). Students in problem-based learning are actively absorbed in solving problems while developing problem-solving skills (Tarmizi & Bayat, 2011). Mertz (2006) further claims that through engagement in complex problems students use their imagination to support critical evaluation of the issue at hand. This influences them away from the idea of a simple linear method of science. A guided problem-based learning approach was implemented in a business class to explore its impact on students' critical thinking skills and content knowledge. Students taught prior to implementation were compared to those learning in the current traditional method. Results indicated that guided problem-based learning approach inspired learning. Students in this group performed better on the department final exam with improvement in their critical thinking skills and their group task performance (Nargundka, Samaddar & Mukhopadhyay, 2014).

Klegeris, Bahniwal, and Hurren (2013) conducted a quantitative pre/post design study to investigate the effects of tutor-less problem-based learning on problem solving skills. The data analyzed using the Generalized Linear Model Randomized Block design revealed a statistically significant difference between the average scores obtained at the beginning to end of the term. Data was collected across four different third year courses (human kinetics, chemistry, sociology, and biochemistry) out of which three courses were assigned to the control group (Chemistry, human kinetics, and sociology) and one course (biochemistry) to experimental group that used tutor-less problem-based learning. Two problem-solving test were created using questions from the *Program for International Student Assessment* (PISA) (Organization for Economic Co-operation and Development [OECD], 2004). The test comprised of four problems (six questions) each that was administered at the beginning then at the end of the semester. As indicated through analysis, students in the experimental group obtained higher scores in generic problem-solving tests after attending a large biochemistry class that involved tutor-less problem-based learning while the scores of the control group without problem-based learning showed no improvement.

There is still a lot of debate about conceptual knowledge acquisition in problem-based learning especially regarding knowledge of the basic sciences, since some studies point to a small difference in favor of lectures. A university in São Paulo State, Brazil, De Camargo Ribiero (2008) employed a qualitative case study to examine a partial implementation of problem-based learning in an electrical engineering course. In this study, students' perceptions regarding advantages and disadvantages of using problem-based learning as a partial instructional approach were investigated. The class comprised of 38 students (35 males and 3 females) between the ages of 20–23. The data source comprised of an open-ended questionnaire to gather students' opinions about the module, their opinion about problem-based learning, and its capacity to accomplish the module goals. Improvement suggestions from classroom observations during the course were also documented. The results showed that 79% of the students considered problem-based learning module good or very good, while 16% expressed it was regular, and 5% were not satisfied. Also, 68% of the students agreed that the problem-based learning module met its goals of developing content knowledge, skills (problem solving, communicative, teamwork, self-directed, and life-long learning), and attitudes. In terms of disadvantages pertaining to problem-solving learning module, students expressed it was time consuming, the workload was extensive, it covered content versus the depth, and teacher facilitation was not balanced. In addition to knowledge acquisition, students developed a deeper understanding of specific content through learning. Also, the teaching assessments along with activities were aligned in a problem-based learning environment (Biggs, 2003; Biggs & Tang, 2007).

A three-year long qualitative study conducted by Pepper (2010) focused on undergraduate students' enjoyment, engagement, plus perceptions regarding the learning experience. Problem-based learning was a partial inclusion in the curriculum rather than a complete integration. The outcomes revealed that majority of the students enjoyed working in groups, sharing ideas, being self-directed learners, and the problem-based activities performed in the classroom. Students disclosed the elements of independency by gathering of new information while sharing new ideas, which prompted them to be engaged enhancing their learning experience. The author also noted that although it was not a component of the research study, they noticed the students' semester grades were similar to prior cohorts before implementation of problem-based learning (Pepper, 2010).

As evident in the research presented, problem-based learning activities can be time consuming and require a lot of work. Yet, the self-regulated learning environment and group discussions tied with interactions can motivate students to learn. Consequently, this can have a positive impact on students' performance. Likewise, during a problem-based learning experience, it is not just the environment that influences learning and interaction among students, the problem itself plays a very critical role.

Sockalingam, Rotgans, and Schmidt (2011) examined the five problem characteristics: (1) problem clarity, (2) problem familiarity, (3) the extent to which the problem stimulated group discussion, (4) self-study, and (5) identification of learning goals. They explored students' achievement-related classroom behaviors, as well as academic achievement in a problem-based setting to understand what elements of the problem encouraged enhanced learning with interaction and discussion. The population consisted of 5,949 first year polytechnic students (51% female and 49% male) with an average age of 19 years across 170 courses that applied problem–based learning curricula. Three instruments (measure for quality of problems, achievement-related classroom behavior measure, and academic achievement measure) were used to collect self-reported data. Path analysis was conducted to test the path that created a good model fit leading to statistically significant results across all path coefficients. The results indicated that the problem clarity variable yielded more group discussions, identifiable learning goals, and self-study as compared to the problem familiarity variable. This study outlines that for problem-based learning instructional methodology to be successful, the learning and assessment must be aligned as well as the problem must be clearly stated and defined (Biggs, 2003; Biggs & Tang, 2007; Pepper, 2010; Sockalingam, 2011).

PBL Research in Teacher Education

Teachers are the driving force in the classroom; therefore, their role is central to the learning process. Goodnough and Nolan (2008) assert teachers are critical agents through whom educational reforms transpire. Studies in teacher education have explored achievement, attitude towards content, challenges faced by teachers, and teacher content knowledge.

An earlier study conducted by Peterson and Treagust (1997) applied problem-based learning approach to a unit in science preservice teacher program. This enabled them to develop and apply components of the knowledge base for teaching and pedagogical reasoning. They established that problem-based learning implementation was successful in assisting teachers to acquire their knowledge base for teaching and pedagogical reasoning ability. These teachers were also able to consider these two areas together when resolving a problem. This was a qualitative case study design that used whole group data such as: student journals, preservice teachers' instructional materials, field observation, and written questionnaires for analysis. In addition, five teachers were selected for semi-structured interviews to delve deeper into their pedagogical reasoning. Similarly, Bilgin, Senocak, and Sozbilir (2009) reported on preservice teachers' content knowledge about gases along with preservice teachers' attitude towards chemistry. The results illustrated that experimental problem-based learning group achieved better on measures of conceptual knowledge, yet the groups were not significantly different in their ability to solve quantitative problems about gases. There was also a positive increase in attitude towards chemistry in the experimental group as compared to the control group. The researchers compared the group learning about gases through problem-based learning to a group of students learning through traditional instruction. The following three instruments were used to gather data (gases diagnostic test, chemistry attitudes scale, and scales specific to students' evaluation of PBL). Findings from both studies demonstrate that problem-based learning integrated in teacher education programs can enrich pre-service teachers' content knowledge while developing a positive attitude towards science.

Research is lacking in the area of teacher implementation of problem-based learning in the classroom (Ertmer, 2010). The study by Ertmer (2010) was sought to address this need. Ten in-service middle school teachers were selected from a pool of teachers to evaluate what factors contribute to their motivation to adopt a technology integrated problem-based learning program and what strategies they utilize to implement it. Researchers (Liu, et al., 2012) discovered four factors that effected teachers' motivation to adopt the technology integrated problem-based learning approach. The new program was designed to address their needs with technical support availability on campus. The instructional methods alignment with pedagogical beliefs fosters the development of problem-solving skills. It also established that students' needs are met and they are challenged. The observation data showed that the teachers provided facilitation throughout the learning by asking questions, providing encouragement, and endorsing social interaction as the strategies for implementation. Furthermore, the teachers created a classroom environment to support learning combined with collaboration.

Problem-Based Learning Research in K-12

Over the years interest in problem-based learning has increased because of its close alignment with many educational reforms (Hmelo-Silver, 2004, 2012; Savery, 2006; Torp & Sage, 2002). The Center for Problem-Based Learning at the Illinois Mathematics and Science Academy was the first to introduce plus endorse problem-based learning for a K-12 environment (Illinois Mathematics and Science Academy, 2002). Since then, problem-based learning has been employed in various content areas in elementary, middle, and high school education. However, Li (2012) asserts that many studies that have presented empirical data have focused on benefits of problem-based learning without ample information or details. He goes on to say that problem-based learning still remains a “black box” (Li, 2012, p. 89). This is a similar sentiment supported by an early supposition made by Araz and Sungur (2007) claiming that there is need for more empirical research.

Jezembek and Murphy (2013) conducted a meta-analysis and reviewed empirical studies which involved school-aged children. The results of the analysis found that problem-based learning could have a positive influence on students’ academic and personal development. The authors conducted a database search to find studies that evaluated problem-based learning as a curriculum as well as investigated the impact of problem-based learning on children’s academic and personal development. Although the search found 126 studies, after a narrative literature review only six studies fit the research criteria. Among these six studies, only one was conducted at the elementary level while the rest at the secondary level. Also, only two studies took place within the United States. The results did reveal pedagogical practices informed by problem-based learning could have a positive influence on learners' personal and academic development.

At the elementary level, a quantitative study that compared problem-based learning to traditional approach found that students in problem-based learning classrooms had higher academic achievement and performance skills scores in science compared to those placed in traditional classrooms. The students in problem-based learning environment also had higher reasoning scores compared to those in the traditional learning environment (Araz & Sungur, 2007). Similarly, Zhang et al., (2011) studied the effect of problem-based learning on students' science content knowledge of earth's materials in a kindergarten class. This was an action research study that took place in a single kindergarten classroom. The analysis of students' pre-post assessment combined with class discourse revealed that students' content knowledge on the topic had improved, while the discussion and teacher facilitation had assisted students' development of questioning skills.

Wong and Day (2009) reported findings from a study conducted at a Hong Kong middle school, which compared students' science achievement scores in problem-based learning to lecture-based learning. The results of this study suggested that problem-based learning group showed significant improvements in students' comprehension and knowledge application over an extended period as compared to lecture-based learning. Additionally, the knowledge retention in problem-based learning was more favorable as compared to the traditional teaching approach.

Forrester (2004) points out that characteristics of problem-based learning such as independency, discourse, and active involvement help students perform better. This in turn promotes positive attitudes towards learning. Liu, Hsieh, Cho, and Schallert (2006) explored the effects of problem-based learning environment enhanced with technology on middle school students' self-efficacy, attitude towards science, plus achievement. They reported that there was no significant difference in students' attitude toward science. Moreover, their attitudes towards science were positively correlated with self-efficacy. In terms of achievement, self-efficacy was found to be a statistically significant predictor for achievement. A mixed-methods study that utilized three instruments including, science achievement, self-efficacy scale, and attitude towards science was conducted. The analysis displayed that students in the technology enhanced problem-based environment had an increase in science achievement along with self-efficacy for learning science.

Tarhan, Ayer-Kayali, Urek, and Acar (2008) examined the effectiveness of problem-based learning on students' understanding of intermolecular forces, their alternate conceptions about intermolecular bonding, and their beliefs about problem-based learning. The findings from both the posttest and questionnaire showed that PBL is effective on students' achievement, remedying formation of alternate conceptions, and enhances social skills. More recently, Ferreira and Trudel (2012) implemented problem-based learning in a high school chemistry class at an all-male Catholic high school. Using a mixed-method design, they examined the impact of problem-based learning on students' attitudes, problem-solving skills, collectively with their perceptions pertaining to the learning environment. They found that problem-based learning resulted in a significant increase in student attitudes toward science and problem-solving skills. The students in the study also benefitted from working as a community. Lastly, they enjoyed the learning environment created by problem-based learning.

Comparably, in an evaluative case study of sixth grade students, Simons, Klein, and Brush (2004), discovered that with effective implementation of problem-based learning, sixth grade learners experienced academic achievement; thus had a positive attitude. In this study, student attitude surveys, posttests, interviews, and observations to study instructional strategies were used to examine teacher and students' attitudes along with student achievement during a hypermedia problem-based learning unit. While, Azer (2009), reported on fifth, sixth, and seventh grade students' perceptions about problem-based learning related to students' characteristics, such as gender, age, and first language. Although, the overall perception of problem-based learning was positive amongst the students, significant differences were found between grade levels.

Problem-based learning research has also been conducted in mathematics. A causal experimental design was employed to study nine-year old Slovenian students' cognitive performance and attitude while learning mathematics through PBL. The experimentation involved 179 students randomly divided into a control and experimental group. The researchers (Cotic & Zuljan, 2009) discovered that students in the experimental group, which implemented problem-based learning approach, were more successful in solving difficult mathematics problem as compared to the control group. Nonetheless, there was no difference on the students' ability to use basic computing operations and no statistically significant difference on their attitude towards math.

The use of technology to support learning has grown over the years with attention given to how it can impact student learning. Technology has been integrated in problem-based learning in many forms and content areas. Brown, Lawless, and Boyer (2013) examined if a technology enriched problem-based learning approach can have a positive impact on middle school students' interest toward science, self-efficacy towards writing, as well as stimulate their use of technology as a learning tool. A quantitative research design that integrated problem-based simulation into a face-to-face learning environment. The issues discussed through the simulation included: economies, human rights, health, and environment. The analysis demonstrated a positive impact on students' interest toward science with greater self-efficacy.

Likewise, in another study (Gürsul & Keser, 2009) explored students' academic achievement in math in a face-to-face problem-based learning environment as compared to an online problem-based learning environment. The results indicate that the achievement level of groups in an online environment had higher achievement scores in math as compared to the face-to-face group.

Problem-based learning has been employed around the globe to teach wide range of academic levels and areas to increase content knowledge. This is proven by the extensive research emphasized in this area. It promotes high-order thinking skills, which yield enhanced comprehension with reasoning of the subject matter. Given the potential benefits of this pedagogy, further investigation to examine if similar benefits can be reaped if applied to assimilate content areas is becoming necessary.

CHAPTER 3

STEM EDUCATION

What is STEM?

Technological advancement and economic development in today's society is driven by science, technology, engineering, and mathematics. The real world concepts with experiences acquired through these disciplines are central for developing 21st century skills. Not only does knowledge in these areas provide a stable and competitive position in the global market, it contributes to the development of deeper understanding of worldly phenomena. The skills acquired from these fields can be utilized for creating new techniques to innovate and discover solutions to worldwide problems.

In K-12 education, focus on science, technology, engineering, and mathematics (STEM) are key components that promotes students' development of skills needed for their future careers. Through engagement in these fields, students can develop the ability to think critically, solve intricate problems, and drive advancement that maintains a steady progression of society. Hence, a sound understanding of each of the STEM fields is vital for effective development along with advancement to occur.

Despite the overwhelming support STEM disciplines have received in K-12 education, there is little consensus on the definition of STEM. This confusion is partly due to the impression that the current definition of STEM lacks clarity and precision (Sanders, 2009). An understanding of the meaning of STEM with a history of its usage with implementation must be researched in order to truly understand it's potential.

Definition of STEM

STEM education can play a huge role in the American schooling system by developing a strong partnership between the branches of STEM. However, STEM education is complicated to define because of the various meanings that exist between educators, researchers, politicians, and agencies. For approximately two decades, the *National Science Foundation* (NSF) has used the acronym STEM to refer to the individual STEM disciplines (Sanders, 2009), while educators have utilized STEM for describing projects and curricula. It has lacked a clear understanding of an integrated approach, because of the different interpretations. According to Sanders (2009), educators should refer to 'STEM' as 'STEM education' to clearly differentiate from the individualized science, technology, engineering, and mathematics disciplines in the workforce. Another common misunderstanding in regards to STEM education is the representation of the 'T' in the STEM acronym. The 'T' in STEM refers to the use of computing technology or computers (Daugherty, 2010; Sanders, 2009).

Wang, Moore, Roehrig, and Park (2011) stated that the description of STEM education falls into three categories: (1) STEM education is an integration of science combined with mathematics content implemented through a technology curricula, (2) It is a blending of academic coursework with career and technical education (CTE), (3) It is an application of concepts derived from individual STEM disciplines into other areas.

The first interpretation of STEM education applies to the amalgamation of science, mathematics, and technology without the inclusion of engineering. Although this explanation makes sense and is most often utilized, Czernik, Weber, Sandmann, and Ahern (1999), assert regardless of the many endorsements made by educators regarding this integration, few empirical studies exist to substantiate this claim. The second explanation of STEM education refers to an academic coursework combined with career-technical education (CTE). The benefit of this assimilation is to make college an option for many high school graduates. Stern and Stearns (2006) reported on the potential advantages as well as challenges of integrated academic and vocational education. Although, vocational education programs are not intended to yield undergraduate or advanced degrees, as of March 2004, approximately 30% of 25 to 34 year olds that completed a vocational program had obtained either bachelors or advanced degrees. They found that students who combined academic coursework with CTE performed better in high school. There was no further evidence available to indicate if this combination in curriculum improved the chances of college enrollment or completion.

The third category of STEM, in which ideas from each individual domain of STEM is gathered and applied to other disciplines, is often referred to as *STEM integration*. This interpretation of STEM education is considered to be the modern conception of STEM, in which purposeful combination of these specific disciplines are applied to solve real-world problems (Breiner, Harkness, Johnson, & Koehler, 2012). Breiner et al. (2012) asserts that the merger between the fields of science, technology, engineering, and mathematics as one unit will promote teaching and learning of these disciplines as an entirety while inclusion of non-STEM disciplines, such as history and language arts in this union can be a powerful means for fostering STEM literacy. Since secondary education across the U.S. is departmentalized, teaching STEM subjects in a holistic manner can be challenging, but requires a lot of effort with collaboration from teachers. Nonetheless, this partnership is necessary for successful implementation of STEM education.

For example, in an effort to promote this integrated definition of STEM education, the Massachusetts Department of Education (Conaway, 2007) collaborated with partners across the state to strengthen STEM education among educators and students. Programs were designed for teacher training and students to increase content knowledge and proficiency in STEM subjects. Additionally, standardized assessment policies and teachers' licensure requirements were amended. This meant that the graduating class of 2010 and beyond would be required to pass proficiency exams in biology, chemistry, physics, or technology/engineering. Considering this, it would be mandatory for elementary and special education teachers to pass the mathematics section of the teacher licensure exam to obtain/maintain a teaching license. In order to track students' progress, Massachusetts Department of Education decided that they would participate in the Trends International Mathematics and Science study (TIMSS). They would work with the Board of Higher Education to develop a school–to-college database that will allow the state to track their high school graduates into state colleges in conjunction with forming a relationship with between high school performances and college outcomes (Conaway, 2007).

The various definitions of STEM education in conjunction with its implementation discussed in this chapter continue to be present today. These definitions have emerged over the years due to the reform efforts and challenges presented because of STEM implementation in K-12 settings.

Reforms in STEM Education

During the past decade, there has been a significant amount of attention given by educators, researchers, and politicians towards STEM content areas (Kuenzi, 2008; Sanders, 2009; The White House, 2009). This increased attention is due to the concern that many secondary school students fail to reach proficiency in math and science (Kuenzi, 2008). As reported on the 2012 Program for International Student Assessment (PISA), the United States ranked 27^{th} in math literacy and 20^{th} in science literacy among the 34 countries that participated. Students' performance within STEM subjects is startling, but contributes to the lack of organized science across K-12 schooling (National Research Council [NRC], 2012). This also indicates teachers' lack of content-based knowledge (Sanders, 2009), as they are not able to provide the necessary education. There are approximately 1.7 million U.S. elementary school teachers (Soares, 2011), yet only a few of these school teachers specialize in STEM subjects. In addition, there are about 1.3 million middle and high school teachers in public schools out of which only 477,000 are estimated to have a primary assignment within mathematics or science (Soares, 2011). Sanders (2009) further claims that this lack of effective practices coupled with teacher quality has caused disconnect in schools between STEM disciplines providing a deteriorating American schooling system with regards to STEM education.

Educational improvement efforts have begun to take shape in order to address the needs in STEM with strategies to increase both the number of qualified STEM teachers, student proficiency, higher-order thinking skills, attitude, and motivation in STEM subject areas (Potvin & Hasni, 2014; Soares, 2011). These include an *Educate to Innovate* campaign led by President Obama along with his administration to help students excel in STEM fields (The White House, 2009). Development of *Common Core State Standards* (National Governors Association, 2010) for mathematics, *National Educational Technology Standards* (International Society for Technology in Education, 2008) for technology and the conceptual framework for K-12 science education (National Research Council [NRC], 2012) along with subsequent standards themselves (NGSS Lead States, 2013). The objective behind all these efforts is to increase student performance in math and science with an end result to persuade more students to acquire degrees in STEM areas. The new conceptual framework is designed to promote interdisciplinary practices as well as develop students' interest in STEM disciplines. Most importantly, its goal is to increase student achievement in math and science.

Conceptual science framework. The new science framework defines the "foundational knowledge and skills" (NRC, 2012, p. 2) in science and engineering that students in K-12 should acquire by the end of 12th grade. There are three major dimensions recommended in this framework to foster meaningful learning in science and engineering listed below:

- Scientific and engineering practices;
- Crosscutting concepts that unify the study of science and engineering through their common application across fields;
- Core ideas in four disciplinary areas: physical sciences; life sciences; earth, and space sciences along with engineering, technology, and applications of science (NRC, 2012, p. 2).

The aim of scientific and engineering practices in the framework is to assist students to form a relationship between science and an engineering discipline; similarly to understand that a distinct process for conducting scientific investigation does not exist. To emphasize this concept, different knowledge-based practices are required for scientific investigation in each discipline. There are eight essential practices in the new framework for students to engage in and recognize the process of developing scientific knowledge (NRC, 2012).

The second dimension of the framework includes seven crosscutting concepts. The objective of the crosscutting concepts is to provide students with connections that are related across disciplinary areas and help them bridge science and engineering. They are organized to link across the various domains at each grade level. Their purpose is to provide students with the understanding that science and engineering have similar practices across fields. Additionally, it is designed to help them develop an understanding of core ideas in each discipline (NRC, 2012).

The core ideas are the third and final dimension in the framework. The ideas are selected based on the multiple associations they form within science or engineering disciplines. They are applicable across STEM content areas with an objective to foster students' connections with real-world experiences (NRC, 2012).

This inclusion of engineering and technology in the new science education standards along with the natural sciences signifies the importance of developing an understanding of a society shaped by humans and recognizing the value of using an integrated approach for teaching and learning STEM education content areas (Lachapelle, Sargianis, & Cunningham, 2013).

STEM Integration in Science Education

Science is around at every instance, used for understanding the world around us. It is not just knowledge of accrued facts, but rather a process that contributes to an overall explanation of why and how things work the way they do. A comprehensive understanding of science develops with a realization that science does not prove anything absolute; all ideas can be revisited and amended in light of new evidence (Chalmers, 1999). Nevertheless, science alone does not explain ideas, phenomenon, or progress society. It is a combination of science, technology, engineering, and mathematics (STEM) that play a significant role of working together to enlighten our knowledge of the world that humans employ to progress society. Most recently, there is a push for an interdisciplinary approach for teaching science, technology, engineering, and mathematics (STEM) in K-12 education.

Science, Technology, Engineering, and Mathematics (STEM) education in science education is vital for our future advancement. Advocates of this assimilated approach believe that learning in this manner becomes connected, consequently promoting a more all-inclusive meaningful experience, which stimulates the learner to engage in or relate to real-world experiences (Furner & Kumar, 2007; Smith & Karr-Kidwell, 2000). This integration can improve students' academic achievement, develop students' interest in STEM related fields, and enhance their motivation to learn (Stinson, Harkness, Meyer, & Stallworth, 2009). Frykholm and Glasson (2005) claim students' experiences are enriched as they develop a deeper conceptual understanding in math and science through interdisciplinary learning. These multidisciplinary experiences can equip students with essential skills and knowledge necessary for the global economy (Becker &

Park, 2011). Also, content along with context integration methods in science education can aid students in recognizing the interwovenness of STEM disciplines (Moore & Smith, 2014). This interconnectedness of STEM fields can incite an innovative way to teach and develop students' understanding in science (Roberts, 2013).

Recently in New York City, to endorse diversity through STEM disciplines, New York College of Technology (CITY Tech) embraced an interdisciplinary approach to learning while emphasizing the integration of STEM knowledge. The institution adopted a philosophy based on the assertion that,

> Interdisciplinary studies nurture and enhance the ability to assemble (locate, organize, and evaluate) ideas and information from disparate sources into a coherent whole; the ability to function within a team setting; the ability to apply knowledge and skills to real-world problems; and the ability to effectively communicate complex cross-disciplinary problems both orally and in writing. (Lansiquot, Blake, Liou-Mark & Dreyfuss, 2011, p. 20)

Furthermore, STEM integration in science education can create a partnership across disciplines, it can encourage collaboration, promote community involvement, organization in teaching and learning leading to a STEM literate society. As Trevey (2008) asserts, education in STEM is important, because the dependency on technology is exponentially growing, thus the growth of our future economy depends on proficiency in STEM content areas. Economists agree that innovation in America cannot occur without a strong background in STEM education (Trevey, 2008). With the inclusion of 'E' in the new K-12 science framework (NRC, 2012), we have maximized the potential to inspire students to pursue STEM careers as well as prepare students to be successful in a post-secondary setting (Moore & Smith, 2014). This unification has articulated the importance of developing a deeper connection among the STEM disciplines by including engineering and technology practices in science education. Rockland, Bloom, Carpinelli, Burr-Alexander, Hirsch, and Kimmel (2010) state this incorporation of engineering practices in science and mathematics curriculum can develop students' interest in STEM. It can assist them in making connections between classroom activities and the real world concepts. While researchers (English et. al., 2013) claimed that inclusion of engineering practices could foster students' appreciation for engineers plus providing them with the awareness of how they have improved society.

Science and engineering. For many educators the inclusion of engineering practices in the new science education standards (NRC, 2012) may be difficult to understand. Educators may find these engineering practices too complex with difficulty in application. However, experts believe that there are several ways that engineering can support science education (NRC, 2012). Engineering integration in K-12 education can maximize creativity, provide hands-on opportunities, and offer a real world context for students (Ringwoood, Moaghna, & Maloco, 2005). Engineering activities along with lessons can also build confidence and self-efficacy among young learners allowing them to be successful in advanced math and science courses in their later years (DeJarnette, 2012). A report presented by the National Research Council (Katehi, Pearson, & Feder, 2009) reviewed 34 engineering programs that embedded engineering interwoven in science, technology, and math. It described three main principles of K-12 engineering education. First, K-12 engineering education should emphasize engineering design. Second, K–12 engineering should incorporate important science, mathematics, as well as technology concepts and skills. Finally, K–12 engineering should align with 1) systems thinking, 2) creativity, 3) optimism, 4) collaboration, 5) communication, and 6) attention to ethical considerations to promote engineering practices. These practices in K-12 education can support the development of a diverse student body, enhance teacher knowledge, yield interest in STEM among students, while strengthen our nation's contribution to the global engineering workforce (American Society for Engineering Education, 2006; English et al., 2013).

Three private schools participated in a three-year longitudinal study in Australia where the researchers (English et al., 2013) reported that since students had an increased understanding of the properties associated with simple machines, they were able to identify multiple simple machines. This enabled them to form links between physical materials, abstract concepts, and developed an awareness of design constraints. The researchers explored students' explanations of the simple machines used in their design with an evaluation of their design. Through engineering problem solving, students were required to design, construct, and evaluate their trebuchet. This research utilized a qualitative research method with data sources including audio and video recordings, students' workbooks, images of students' creations, and teacher interviews. Similarly, Lottero-Perdue, Lovelidge and Bowling, (2010) discovered that students constant evaluation of their design with respect to the engineering design process allowed them to comprehend the science concepts more adequately as apparent by their designs. The students employed engineering design process to learn science concepts such as position, motion, force, as well as energy by creating and designing windmill blades. These blades were tested on a windmill apparatus placed in front of a fan. Throughout the experience, students participated enthusiastically with documentation of the steps associated with the engineering design process in their journals. This was a qualitative research study that assessed students' content understanding in science and engineering. The integration of engineering design in both lessons assisted students in grasping science concepts.

In another engineering integration study, it was discovered that student self-esteem increased and their interest grew in electrical and computer engineering after participating in an outreach project. The Computer Science Department at a Turkish University choose students between the ages of 12 -14 via a four stage selection process to participate in a year-long project. A final group of 14 students took two 11-week courses to learn discrete mathematics, science, and logic design. Knowledge from these courses was utilized to design circuits, which helped them to understand the connection between engineering and science, thus increasing their interest to pursue engineering (Inceoglu, 2010).

In addition to self-esteem and interest, Karatas, Micklos, and Bodner (2011) uncovered that the majority of students believed that engineering requires construction of products, linking engineers to builders. Few believed that engineers design or test products as well. Also, students' perceptions regarding the nature of engineering and engineers were volatile and there was possibility of change within the duration of the interview. In this study, researchers used a phenomenological qualitative design to examine sixth grade students' perceptions of the nature of engineering and engineers. The data was collected through semi-structured interviews and field notes. During the interview process students were asked to first draw an engineer conducting a task and then explain their drawings.

The foundations of science and engineering are complementary. For example, like scientists, engineers engage in scientific practices to understand the relationship of knowledge. They explore areas in general then utilize technological tools along with technology for discovery and advancement (Rockland et al., 2010). Based on these commonalities, it is vital to expose students to engineering practices in K-12 educational levels. This would help students form correlations between the two fields and how they have developed society. In addition to engineering, technology has become an essential component of society as well. Consequently, technological knowledge has become a necessity in today's world.

Science, technology, and engineering. One of the core disciplinary ideas presented in the new conceptual framework (NRC, 2012) is technology and engineering with their application in society. Society has made tremendous advancement in scientific discovery through development of new products and processes. Technology and engineering are the two key factors that have contributed to this evolution by translating scientific knowledge into action.

Technology and engineering integration in science can optimize learning and allow students to comprehend how scientific advancements occur. Conferring this view, Lipton (2005) claimed that the American public would unanimously agree that school should include a technology curriculum and proposed a four-letter acronym, TIDE, for *Technology, Innovation, Design, and Engineering*.

Although there have been a number of pros and cons associated with technology and engineering, the word *engineering* today has become a buzzword within technology education (Sanders, 2009). Many advocates of technology and engineering believe that this acronym (TIDE) should be a component of technology education (Lipton, 2005). Litowitz (2008) proposed that engineering should be the focus of technology education, because the word engineering is relatable, "engineering is sexy, engineering has curb appeal" and because of this people are buying engineering (p. 24). This is evident by programs such as, *Project Lead the Way*, *Engineering by design,* and *Project ProBase*, all focus on creating pre-engineering curriculum for high school classrooms and have yielded positive results in a K-12 environment (Dearing & Daugherty, 2004; Rogers 2005).

Whereas technology education supporters claim engineering should not be a part of technology education, since the field is already divided within. The insertion of engineering would add more confusion to the discipline (Spencer & Roger, 2006). According to them, inclusion of engineering would delay technology education from being established as a recognized program and elongate the pursuit to define itself. Hence, technology education should not comprise of engineering (Spencer & Rogers, 2006)

Nonetheless, several states have added engineering to their technology education programs. Indiana changed its technology education program to '*Engineering and Technology Education'*. Organizations such as, the International Technology Education Association (ITEA) also changed its name to the International Technology and Engineering Educators Association (ITEEA) because many members in the organization were already working with engineering related curriculum (International Technology Engineering Education Association, 2010).

Engineering and technology can be beneficial for teaching and learning. It helps to deepen students' content understanding and achievement scores. A pilot study established that pre/posttest scores showed that those students in the robotics group did significantly better in posttest than those in the control group. Researchers (Barker & Ansorge, 2007) examined students' content knowledge in science, technology, and engineering through engagement in informal afterschool engineering robotics curriculum. The students ranged from 9-11 years of age and the study employed a pre/post quantitative design. Similarly, in another study, students' concept understanding, engagement, and retention of core concepts increased after being involved in an engineering design-based class. The researchers (Mehalik et al., 2008) inspected middle school students' understanding of science concepts, students' engagement, and retention. Students from across many schools were engaged in a scripted inquiry versus an engineering design-based inquiry, in which they build electrical alarms to learn concepts in electricity.

Furthermore, science content knowledge, engineering, and technology can develop students' process skills and thinking skills. A study conducted by Sullivan (2008) analyzed quantitative pre-post data during a robotic challenge. The students attended an intense robotics course during a summer camp. The finding suggests that through this challenge, students' systems understanding increased. Also, this led to a positive effect on students' thinking and process skills.

Although advocates (Spencer & Rogers, 2006) of technology education might argue that engineering should not be a part of technology education, the studies reveal that technology and engineering integration in science can be beneficial. It can strengthen students' science concepts and increase achievement. With the addition of engineering and technology in the *Next Generation Science Standards* [NGSS] (Achieve, Inc., 2013), it would be best to incorporate both technology and engineering in the science curricula.

For many years, science and mathematics have also been integrated for science teaching and learning, primarily the concepts of motion and measurements (Berlin & White, 2012). Higher-level mathematics is also used to derive engineering concepts. This assimilation has resulted in a positive impact on students' learning and attitudes (Furner & Kumar, 2007). With so much correlation between these subjects, it is necessary to incorporate concepts that cut across disciplines.

Science, math, and engineering. The recent decline of students pursuing engineering degrees in the United States has caused great concern for higher-education authorities, government organizations, and officials. Similar to the historical crises of Sputnik 1959, that brought a reform in science and technology (Berghel, 2014). This distress has led to many improvements in sciences and mathematics programs, especially since our TIMSS scores in mathematics and science are lower compared to other countries. There is push to increase student performances in these areas. Conversely, with so much crosscutting between these subjects and their alignment with the engineering field, it is ideal to embed engineering into science and mathematics practices (Roberts, 2013).

Students' achievement in mathematics has been deficient since the early 20^{th} century. More recently, American students' mathematics performance has been compared on an international level showing American students being outperformed by many Asian and European countries (McGee, Polly, & Wang, 2013; Stigler & Hiebert, 2009). Researchers have addressed the need to improve students' performances in science, mathematics, and engineering as well to inspire students' interest in these disciplines (Goonatilake & Bachnak, 2012). A study was conducted to explore students' interest in engineering and content knowledge in abstract chemistry concepts. Findings from a post chemistry assessment and an interest survey showed that students made significant gains in their understanding of abstract chemistry concepts. Additionally, their interest in engineering improved through engagement in an eight-week *Heating and Cooling Systems* science unit. This intense chemistry unit explored ideas such as atomic interactions, reactions, and energy changes during reactions. Student assimilated ideas in mathematics, science, and engineering design to create a heating and cooling system. This allowed students to form connections across disciplines. These high school seniors' observational data displayed that this intervention heightened their interest to pursue careers in engineering in college (Apedoe et al., 2008).

An instrument was created to assess high school students' perception of engineering after participating in an engineering design problem as well as their content knowledge. The researchers (Hernandez, Bodin, Elliott, Ibrahim, Rambo-Hernandez, Chen, & Miranda, 2014) described that the students' perceptions changed for the positive through this intervention and improved their content knowledge. The exploratory factor analysis conducted to verify the scale's validity confirmed the reliability of the instrument. Students from five area high schools enrolled in science, mathematics, technology, and engineering participated in this study. The intervention involved students to work in teams to solve complex engineering problems, which included concepts in engineering, science, and math. A quantitative instrument was employed that was designed particularly for this intervention to assess perceptions and content knowledge in all three disciplines. Both of these studies suggest that content knowledge can improve with discipline integration. However, whether this knowledge acquired is transferable into other situations or disciplines is questionable.

Learning is not a matter of simply acquiring content knowledge, rather the ability to transfer that knowledge across disciplines, situations, and into real-world context. Fortus, Krajcikb, Dershimer, Marx, and Mamlo-Naaman (2005), found that although written assessments yielded significant gains in students scientific knowledge from pre-posttests, the transfer of knowledge for most the students was not successfully achieved. Only 24% of the students gave complete responses to the problem and 37% partially responded while the rest did not provide an answer. This research investigated students' content knowledge and their ability to transfer their knowledge to solve other problems using their mathematics, science, and engineering understanding. Students from ninth and tenth grade science class participated in a design-based unit. The data sources included pre-post written assessments and written problems that students were required to solve. Although this signifies that even though knowledge can be attained through design based engineering integration, knowledge is not easily transferable immediately after one implementation. Thus, more opportunities should be provided for students to enhance their skills and effectively apply scientific knowledge in other areas.

An examination of engineering across disciplines, such as science, mathematics, and technology portrays the potential of an integrated STEM curriculum that can enrich teaching and learning in science, incite interest across disciplines, and increase students' content and scientific knowledge. The existing research also suggests that integrating engineering into science and mathematics classrooms might benefit student learning in science and mathematics (Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006). Consequently, this assimilation of subjects, such as STEM, can be beneficial to science education.

Benefits of STEM Integration in Science

Science, Technology, Engineering, and Mathematics (STEM) integration in science has the potential to make a difference in students' content knowledge, higher-order thinking skills, and attitudes. A challenging science curriculum with STEM inclusion can stimulate interest in STEM disciplines, enhance students' creativity, and arouse curiosity in young children. It can promote students' to apply cross-disciplinary knowledge in real-world context (Roberts, 2013). Integrated methods offer rich learning experiences, thus increasing students' interest. Also, integrative STEM curriculum has the potential to increase students' achievement in STEM subjects (Becker & Park, 2011). Sanders (2009) claims, that positive interest along with positive attitudes are two components that can improve students' motivation in STEM careers.

Students' STEM content knowledge. The goal across all four STEM disciplines in K-12 education is to improve content knowledge is all areas, help students' develop integrated thinking skills, and prepare them for academic success. Ball, Thames, and Phelps (2008) define content knowledge as "knowledge of the subject and its organizing structures" (p. 391). As students enter the next milieu they will be faced with many challenges; among the many is adequate content knowledge in STEM. Many factors have contributed to students' lack of content knowledge in STEM disciplines, especially engineering, such as quality teachers, instructional practices, and efficient STEM curricula (Rockland et al., 2010). According to Weiman (2012), for an instructional practice to be considered effective, the learner's engagement through intellectual process should be maximized to help foster expertise. While Cotabish, Dailey, Robinson, and Hughes (2013) claim that student content knowledge and performance can improve with content-based professional development. In a classroom, students' content knowledge is dependent on teacher quality and instructional approaches. So, to improve students' content knowledge in STEM, we should focus on the teachers' knowledge and instructional practices.

Wendell and Rogers (2013) found that students that explored science content using LEGO engineering curriculum performed higher on their science content tests as compared to those in traditional science curriculum. A two-year study examined third and fourth grade students' science content knowledge in a LEGO engineering designed curriculum. During the first year of the study the traditional curriculum was implemented and engineering curriculum during the second year. Data collection from both years included pre-post assessments created to assess content knowledge in each implemented science unit. In another study, problem-based learning was utilized and the results indicated that students' content knowledge increased along with more developed technological skills. Eitel, Hougham, Miller, Schon, and LaPaglia (2013) investigated the effect of problem-based learning on students' content knowledge. The students worked in groups to engage in discussions to solve a complex real-world problem. The problem they addressed required them to design a town that had energy and water needs, while taking into consideration possible impacts of climate change on water resources and reduced greenhouse gas emissions. To tackle this challenge, students used simulations, models, conducted interviews with experts, and presented their understanding while creating a website. A rubric was created to assess student groups' content understanding, creativity of design, and communication on the website. Meaningful projects that effectively connect with content develop students' content knowledge. In both of these studies, what led to an increase in content knowledge was the instructional method that engaged students in the learning though exploration and interaction.

In addition to instructional practices, a teacher's content knowledge, teacher quality, beliefs, and preparedness can also have an effect of students' content knowledge. As Diamond, Maerten-Rivera, Rohrer, and Lee (2014) assert that teacher knowledge, and beliefs have shown to effect student achievement.

Teachers' STEM content knowledge. The United States is spending a large amount of money in STEM to address the shortcomings visible in the K-12 schooling system. These deficiencies are being addressed through programs being created for students, new standards adaptation nationwide, and the onset of new STEM research at universities and other organizations. This spike in attention to STEM education is to improve students' content knowledge, higher-order thinking skills, and attitude towards STEM disciplines. STEM integration has the potential to benefit teaching and learning; however, money alone will not alleviate the problem, as teachers' strong content understanding of STEM subjects is imperative.

Shulman (1986) refers to teacher content knowledge as pedagogical content knowledge (PCK). Pedagogical content knowledge according to Shulman (1986) goes beyond subject matter knowledge by addressing knowledge of both the substantive and syntactic dimensions of their disciplines (Shulman, 1986). As he claims, not only teachers need to "understand that something is so, the teacher must further understand why it is so, on what grounds its warrant can be asserted, and under what circumstances our belief in its justification can be weakened and even denied" (Shulman, 1986, p. 9).

According to Cotabish et al. (2013) quality teacher professional development programs have the potential to effect teachers' content knowledge and instructional practices, which can lead to an increase in student learning. Cotabish et al. (2013) found statistically significant gains in students' science processing skills, science concept understanding, and science content knowledge. The study investigated the effect of a one-year STEM teacher professional development on students' learning. Seventy teachers were randomly selected from two school districts from grades second to fifth and were assigned to a treatment and control group. This was a qualitative study that employed a pre-post design to gather data using three instruments (Fowler Test, curriculum based assessment, and science content assessment). Students in treatment group class out performed those in the control group. Teacher content knowledge and quality teaching reflects on students' content knowledge as illustrated by this study.

Heller, Daehler, Wong, Shinohara, and Miratrix (2012) also discovered that teachers' science knowledge increased after participating in a professional development, resulting in a positive effect on students' content knowledge. Eight professional development sites were established for this study; four in the eastern states and four in the western. There were 265 teachers in total that were randomly separated into a treatment and control group for each region. The professional development took place over three courses where data was collected prior to each course and after. The data was comprised of science content assessments and written explanation to questions, which was then analyzed using qualitative and quantitative analysis. Likewise, a mathematics and science content professional development that provided teachers with activities that can be implemented in the class immediately, reported that teachers were very satisfied with the workshop and showed their STEM content knowledge increased. This study explored teachers' STEM content knowledge and pedagogy after participating in a STEM professional development that employed discovery and active learning strategies. In a two-week long workshop 74 teachers engaged in hand-on activities. The first half of the workshop focused on biology and the second half on geometry. A Likert survey was created for data collection (Beaudoin, Johnston, Jones, & Waggett, 2013). It is evident from the results of the studies that professional development can influence teaching and learning while improving teachers' content knowledge.

Nevertheless, simply improving teachers' STEM content knowledge is not enough for any educational change to be successful and effective. It is imperative to address teacher quality and preparedness as well. Without quality educators STEM issues cannot be addressed (Trevey, 2008)

Teacher quality and preparedness. Many states are taking action to tackle teacher quality and preparedness by creating STEM training programs, professional developments for in-service teachers, and reforming teacher education programs for preservice teachers (Johnson, 2103). States such as Texas, California, and Ohio have created exceptional programs to promote STEM teachers.

At University of Texas, UTeach program, and California State University's Teach California program are offering scholarships to students in STEM majors; in return these students are required to teacher within the state after graduation (Trevey, 2008). After the successful outcome of the teaching programs in Texas and California, 21 other universities across the U.S. adopted such programs (Schachter, 2011). While in Ohio, the state governor has joined forces with private sectors to build STEM schools, provide professional development to teachers, and attract undergraduate students to pursue degrees in STEM disciplines. Moreover, states are offering incentives to employ quality teachers (Trevey, 2008) while teacher education programs are changing their content and pedagogy to include more mathematics, science, and technology (Berlin & White, 2012).

As STEM makes its way into the classrooms across America, another integral factor in determining its success is teachers' beliefs about STEM. In addition to teachers' content knowledge, quality, and preparedness it is important to investigate teachers' beliefs about STEM education. This is crucial, as they will be leading our youth through this journey of educating them with STEM content knowledge.

Teacher beliefs about STEM. Teacher beliefs can be described as the foundation for conceptual structures (Fishbein & Arjen, 1975). Through direct experience, observation, interaction, and communication with different environments, people develop beliefs that aid in the understanding of and judgment of their surroundings. Subsequently, with this change in beliefs, they are able better evaluate their environment (Cunningham, Schreiber, & Moss, 2005). In the classroom, teachers have belief systems that strongly influence their actions. Previous studies argued that teachers' beliefs and attitudes influence their classroom practices in mathematics and science (Handal & Herrington, 2003; Roehrig & Luft, 2004; Stipek, Givvin, Salmon, & MacGyvers, 2001).

Wilkins (2008) investigated the relationship between mathematics knowledge, attitudes, beliefs, and practices of 481 in-service elementary teachers. The results indicated that teachers' beliefs and attitudes are related to their instructional practices and that teachers' beliefs were found to have the strongest effect on teaching practices. Tuzun (2007) investigated preservice teachers' beliefs by working with 166 preservice science teachers enrolled in science methods courses at five Midwestern U.S. universities. The findings suggest that preservice teachers' confidence level regarding teaching methods and student assessment increased with the number of science courses taken. The preservice teachers were asked to complete the *Beliefs about Teaching* (BAT) survey, created for study purposes. In both studies it was evident that content knowledge is an important contributor to teacher beliefs' and instruction.

Teacher beliefs and attitude directly influences student attitude (Dance & Pfiester, 2013) as well. Those teachers that have negative beliefs and attitudes towards STEM integration would most likely have students that have no interest in STEM education (Nadelson, Callahan, Pyke, Hay, Dance, & Pfiester, 2013). Although limited research has explored teachers' attitude and/or beliefs towards the use of STEM in their teaching. Few studies that have been conducted demonstrate teacher confidence and strong content knowledge in the subject matter influence their teaching of STEM (Stohlmann, Moore, & Roehrig, 2012).

Nadelson et al. (2013) discovered a positive correlation between teachers' knowledge of STEM, confidence for implementing STEM, and efficacy for teaching

STEM. The authors explored teacher confidence, attitude, and self-efficacy for teaching STEM through a three-day professional development. Teachers participated in inquiry based STEM activities during the summer with observations taking place during the school year. There were four instruments employed for data collect such as, a demographic survey, a survey of confidence for teaching STEM, a survey of efficacy for teaching STEM, and an assessment of attitudes toward engineering. While Stohlmann et al. (2012), found that teachers' comfortability for teaching *Project Lead the Way* curriculum was dependent upon effective instructional approaches. Their comfort levels also relied on their desire to continue teaching PLTW curriculum and establish a career in STEM. In this study, Stohlmann et al. (2012) examined *Project Lead the Way* teachers' consideration for teaching STEM. Data sources included field notes, informal interviews, and classroom observations. These two studies reinforce the belief that teachers' self-efficacy, attitude, and comfortability are determined by teachers' content knowledge of the subject matter. Thus, to alter teachers' perception regarding STEM they need to be prepared and have ample knowledge in STEM disciplines.

Nathan, Atwood, Prevost, Phelps, and Tran (2011) found that high school teachers believe that STEM education takes place in formal and informal settings with students who are strong academically more likely to be successful in engineering. Teachers also believed that student interest in engineering develops because of social interactions and family history. Nathan et al. (2011) examined *Project Lead the Way* teachers' perceptions prior to being exposed to PLTW curriculum. They utilized an engineering beliefs survey (EEBEI-T) for data collection to determine changes in teacher perceptions about engineering before and after they attended the summer PLTW institute.

As evident by these studies, quality STEM teacher professional development, certification programs, and teacher education programs can provide teachers' with sufficient content knowledge that can help alter their beliefs and attitudes towards STEM. Quality teachers and their positive attitude towards STEM education can further lead to developing strong and competitive STEM graduates. However, as Epstein and Miller (2011) assert, it must start early at the elementary level. Starting early will be beneficial to STEM learning, selection process, preparation, and licensure programs. This toughness is especially necessary for elementary school teachers.

STEM and Critical Thinking Skills

There are varied definitions of critical thinking in the literature, but it is often referred to as discipline and self-directed thinking (Halpern, 1998; Paul & Elder, 2006). Facione (1990) defines critical thinking as "purposeful, self-regulatory judgment that results in interpretation, analysis, evaluation, and inference as well as explanation of the evidential, conceptual, methodological, or contextual considerations upon which that judgment is based" (p. 2). Critical thinking is closely associated with reasoning, problem solving, and decision-making (Willingham, 2008). Kek and Huijer, (2011) state that a critical thinker is someone that has the ability to solve problems, effectually analyze information, and possesses higher-order thinking skills. Critical thinking skills can be taught, but require the learning environment to be deeply rooted in developing skills as the learning outcome (Biggs, 1999). Additionally, critical thinking skills are transferable to other domains and disciplines (Halpern, 1998). Therefore, critical thinking skills are best when taught in an integrated manner, rather than it being a stand-alone topic or an add-on (Kek & Heuijer, 2011). To cultivate critical thinking, the classroom environment needs to be modified from a teacher-centered to a student centered and critical-thinking centered environment (Jones, 2012). An atmosphere in which students can independently learn, solve problems, collaborate on research, and explore real-world content.

Critical thinking skills are essential to be successful in the 21st century. For STEM graduates to effectively participate in the workforce, they need to not only have sound content knowledge in STEM disciplines, but also be able to engage in scientific practices, have the ability to think critically, and be innovative (Mulnix & Vandergrift, 2014). According to Ramsey and Baethe (2013), critical thinking is a vital skill for a career in STEM. Integrated STEM activities in schools that foster social interaction and exploration can assist in developing students' critical thinking, communication, and problem-solving skills (DeJarnette, 2012). In 2009, during his address to Hispanic Chamber of Commerce President Obama laid out an educational challenge in which he stated:

> I'm calling on our nation's governors and state education chiefs to develop standards and assessments that don't simply measure whether students can fill in a bubble on a test, but whether they possess 21st century skills like problem solving and critical thinking, and entrepreneurship and creativity. (as cited in Barell, 2009, p. 197)

The new science conceptual framework (NRC, 2012) tried to address this challenge by incorporating crosscutting practices that require students to develop and apply critical thinking skills when conducting an investigation, refining an idea or creating, and explaining a design. Like scientist, children should explore data, think critically, make observations, and generate new questions. Pallant, Pryputniewicz, and

Lee (2012) found that through justification of claims and through certainty validations, students' critical thinking skills are enhanced. The 'High Adventure project' conducted in middle and high schools examined students' critical thinking skills through evidence based claims and certainty justification. Through an online simulation that included computational models, students investigated behaviors of sophisticated systems in Earth and Space science. The data source included four pre-post explanation based certainty items embedded in the simulation that required students to make scientific claims and provide evidence, then rate their degree of certainty with justification. A scoring rubric was created to grade their rationales. The integration of math, science, and technology while engaging students in scientific practice can cultivate their critical thinking skills.

Likewise, Duran and Şendağ (2012) also found a significant difference on students' pre-post critical thinking scores. An IT/STEM project funded by National Science Foundation investigated urban high school students' critical thinking skills. The project participants were divided into four groups (Mathematics, Science, Engineering, and Technology), where each group concentrated on three different content specific concepts that were infused with IT applications. A quasi-experimental design with repeated measures employed TERS test (Test of Every day Reasoning), which was administered in the beginning, middle, and at the end of the study. Through this project, urban students significantly improved their critical thinking skills particularly in the areas of inference and deductive reasoning, which simulated their interest in STEM disciplines. Experiences that are interdisciplinary and supported by collaborative problem-based, design-based, and/or inquiry learning strategies can have a significant impact on students' critical thinking skills (Jones, 2012). Moreover, such experiences in addition to developing critical thinking skills can also reduce anxiety and improve students' attitude and content knowledge (Wheland, Donovan, Dukes, Qammar, Smith, & Williams, 2013).

Many studies have explored critical thinking skills and have found positive results (Duran and Şendağ, 2012; Pallant, Pryputniewicz, & Lee, 2012; VanTassel-Baska & Stambaugh, 2006; VanTassel-Baska et al., 2006). A recent study by Kettler (2014) examined gifted and general education elementary students' critical skills in a Texas school district. The outcomes reported a significant relationship between students' math and reading achievement scores with their cognitive ability, yet did not find a significant difference in critical thinking skills between the two groups. However, the author does emphasize the potential for further studies in examining critical thinking skills and instructional interventions in both general and gifted populations.

Attitudes towards STEM

Attitude is a learned trait by an individual either actively or by vicarious experiences and is receptive to change. The term 'Attitude in Science' is a way of feeling about science. Osborne (2003) defines attitude as, "the feelings, beliefs, and values held about an object that may be the enterprise of science, school science, the impact of science on society or scientists themselves" (p. 1053). According to Zacharia and Barton (2004), a number of studies on students' attitudes toward science have been documented in the literature. It is essential to note the changeable nature of an attitude is tied to its explicitness (Wrightsman, 1977). An attitude can be directed to a person, situation, group, policy, or an abstract idea. Even though attitude is changeable, it is not a random occurrence; a specific event or situation has to be the catalyst for a change (Zacharia and Barton, 2004). For example, students do not naturally like or dislike science, they learn to like or dislike it. Students' attitude towards a specific content is influenced by their environment, personal ambition, parental influence, and or effective instructional methods (Papanastasiou & Papanastasiou, 2004).

Science is an important component of STEM; therefore, students' attitude towards science must first be considered in order to promote positive attitudes towards STEM disciplines (Tseng, Chang, Lou & Chen, 2013). This change should begin early, as Jarvis and Pell (2002) state that younger children express more positive attitudes about science than older students do, and middle school students express significantly more negative attitudes than elementary or high school students. Studies have reported positive impact on students' attitude and interest in school through math and science integration (Furner & Kumar, 2007).

Nugent, Barker, Grandgenett and Adamchuk (2010) discovered that's students in the robotics and geospatial technologies camp's long-term intervention group developed positive attitudes towards STEM as compared to the short-term intervention group and the control group. The study investigated the impact of robotics and geospatial technologies interventions on middle school students' attitudes toward science, technology, engineering, and mathematics (STEM). A Likert scale survey was developed to assess students' attitude. Comparably, Chen, Tomsovic and Aydeniz (2014) reported that high school students engaged in engineering design projects had positive attitude towards engineering. Another study was implemented during a summer camp to examine students' attitude towards engineering, in which high school and middle school students conducted projects on electric and renewable energy concepts and worked on an engineering design. Although there was a positive impact on high school students' attitude regarding engineering, this was not the case for middle school students as no significant impact was found. These studies compared change in students' attitude regarding STEM disciplines within a short implementation of engineering design instruction and positive results indicate that integration of STEM disciplines in science curriculum has the potential to change student attitude.

In order for students to be excited and be stimulated to pursue STEM related careers, they must have a positive attitude towards STEM professions. Masnick, Valentia, Cox and Osman (2010) found that high school and college students' had unenthusiastic attitudes towards STEM careers, because they perceived scientific careers lacking creativity and social interaction. Researcher examined a New York state high school and college students' implicit and explicit attitudes towards STEM professions. Date collected through an occupation survey, in which 20 occupations were listed that included scientific occupations, artistic occupations, technical professions, and other common professions. Students using a five-point Likert scale compared pairs of occupations in terms of similarities. Three dimensional career spaces were determined by the analysis. In the first dimension science professionals were rated as highly scientific but not creative, while artistic occupations were rated creative and not scientific. In the second dimension, other careers, such as police officer, were rated highly people oriented versus science professionals not people oriented. The third dimension compared female raters to male raters and no significant difference was found. Knowing how students feel about STEM related professionals can assist in creating opportunities for students to be mentored by practitioners in STEM fields as well as engage in integrated STEM practices that can promote a positive attitude towards science and STEM.

The Present Study

The enrichment of STEM curriculum in our schools can better prepare our children and yield greater interest in STEM content areas. However, we must find an effective teaching mechanism that will help us deliver STEM content to fuel students' interest and comprehension in the subject matter. This research has two objectives in proposing a methodology for integrating STEM content into elementary education. The first goal is to examine the effect of an integrated STEM curriculum implemented through problem-based learning instructional method in comparison to a traditional learning method on fourth grade students' content knowledge, critical thinking skills, and their attitudes towards STEM. The second goal is to investigate the views held by students regarding problem-based learning instructional approach.

The effect of problem-based learning on students' content knowledge and critical thinking skills, particularly in secondary and post-secondary education is discussed in the literature with the effects of an integrated curriculum are well-documented. Conversely, there are limited studies available that examine the effect of problem-based learning in combination with a STEM integrated curriculum developed using the NGSS standards (Achieve, Inc., 2013), employed in an elementary classroom (Duran & Şendağ, 2012; Kettler, 2014; Murphy & Mancini-Samuelson, 2012; Wheland et al., 2013). This study intends to fill the gap in literature by using an assimilated curriculum facilitated through problem-based learning to try to augment students' critical thinking skills and content understanding while developing positive attitudes towards STEM content areas.

Research Questions

The following research questions and hypotheses will guide this dissertation study.

1. What is the impact of problem-based learning as compared to traditional learning on fourth grade students' STEM content knowledge?
2. What is the impact of problem-based learning as compared to traditional learning on fourth grade students' critical thinking skills?
3. What is the impact of problem-based learning as compared to traditional learning on fourth grade students' attitude towards STEM education?
4. How will students describe their STEM integrated problem-based learning experience after implementation?

Hypotheses

1. Fourth grade students that participate in problem-based learning group will show greater gains in STEM content knowledge assessment than fourth grade students that participate in traditional learning group.
2. Fourth grade students that participate in problem-based learning group will show greater gains in critical thinking skills than fourth grade students that participate in traditional learning group.
3. Fourth grade students that participate in problem-based learning group will have a positive impact on attitudes towards STEM than fourth grade students that participate in traditional learning group.

CHAPTER 4

METHODS

Participants and Settings

The setting and participants are an important component of any study. This study's target population was fourth grade students. The selection of fourth grade students for this study was based on three reasons: 1) lack of empirical studies conducted at the elementary level (English et al., 2013; Weiman, 2012), 2) the need to improve science and math scores, and 3) improve fourth grade students' critical thinking skills. Additionally, fourth grade students in the United States consistently score lower on the *Trends in International Mathematics and Science Study* (TIMSS) assessments as compared to students in other countries (Roberts, 2013) making them an appropriate population for this study. School selection was based on accessibility, their willingness to implement the *Next Generation Science Standards* (NGSS), and their desire to actively participate in this study. Thus, the school selection was based on convenience sampling.

Participants

The target population for this study was fourth grade elementary school students from a large school district situated in the Southwestern United States region. There were a total of 105 fourth grade students enrolled (4 classes), all of which were invited to participate in the study. Each fourth grade student was required to obtain parental permission via a consent form and then complete an assent form allowing them to participate in the study. About 95%, approximately 100 students ($N = 100$), provided parent consent and self-assent forms from the total fourth grade population. Out of the

100 students that provided both parental consent and self-assent, 98 fourth graders fully participated in this study (n = 98). The term “fully participated” is defined as those students that provided parent consent and assent, were present for the study activities, and completed all of the study instruments. The demographic of the student population (n = 98) that participated in the study was 76 (78%) White/Caucasian, 8 (8%) Asian/Pacific Islander, 7 (7%) Latinos/Hispanics, 4 (4%) African American/Black, and 3 (3%) American Indian / Native American. The breakdown in gender of fourth grade population is, 48 males ($n_{\text{males}} = 48$) and 50 females ($n_{females} = 50$). Of the participants, 10 (10%) had individualized education plans (IEP), 3 (3%) had limited English proficiency (LEP), and 8 (8%) were eligible for free or reduced-cost lunch.

The teacher that participated in this study was a science specialist for the school and taught all fourth grade classes that were involved in this study. The teacher holds a Bachelor of Arts in Elementary Education and a Master of Science in Secondary Education with an emphasis in Mathematics. She is state certified to teach grades K-8 with certifications obtained in mathematics and general science and has over five years of teaching experience at the elementary level.

School Setting and Demographics

This study took place at a tuition free public charter school within the Clark County School District situated in a suburban neighborhood. Science in this school is taught as a special subject similar to art, music, and library rather than a subject within the classroom. Students in this school had ‘specials’ once a week with each day of the week dedicated to a different special subject (i.e., Monday - Science, Tuesday - Art, etc.).

Additionally, each fourth grade class had the science special a different day of the week (i.e., Class 1 - Monday, Class 2 - Tuesday, Class 3 - Wednesday, and Class 4 - Thursday).

The total population of the school is 764 students of which 387 (51%) are males and 377 (49%) females. The school demographics are as follows: 620 (81%) White or Caucasian, 39 (5%) Hispanic/Latino, 35 (5%) Asians, 30 (4%) Black/African American, 17 (2%) Pacific Islanders, 15 (2%) American Indian / Native American, and 8 (1%) undeclared. Of the total school population, 68 (8%) students in the school have individualized education plans, 29 (3%) have limited proficiency in the English language, and 120 (14%) are eligible for free or reduced-cost lunch.

Design and Materials

The current study employed mixed methods, quasi-experimental, and repeated measures design to address the research questions. For this study, one data analysis would be insufficient to ascertain the effectiveness of problem-based learning with its correlation to student learning. According to Leedy and Ormrod (2005) the quantitative research method is an experimental approach that is utilized to answer questions concerning the relationships between measured variables with the purpose of explaining, predicting, and controlling phenomena. A concurrent mixed method design allows the researcher to collect both quantitative and qualitative data at the same time, which can then be converged to provide an in-depth analysis of the research questions (Creswell, 2009).

The four fourth grade classrooms were evenly and randomly assigned to a control group and a treatment group. The control group had a total of 46 students ($n_{control} = 46$) and the treatment group had a total of 52 students ($n_{treatment} = 52$). The control group was referred to as traditional learning group (TL), which did not include problem-based learning rather a mixture of teacher-centered traditional lectures, individual work, and classroom activities. The treatment group (PBL) was a student-centered problem-based learning approach facilitated by the teacher. The fourth grade classes were randomly assigned to the TL and PBL groups as follows: Monday science class (class 1) – TL group, Tuesday science class (class 2) – TL group, Wednesday science class (class 3) – PBL group, and Thursday science class (class 4) – PBL group. Each class had science once a week on their respective day. During the study, both groups were taught the same STEM integrated content.

In the PBL group, the teacher presented the problem to commence instruction. The teacher in the PBL environment facilitated the learning through questioning and engaging in student discussions, while monitoring students' learning. The students' were also encouraged to ask questions and interact with their classmates. In contrast, the teacher played a different role in the TL group. The teacher delivered the content via slide-show presentations while the students took notes. For content work, students completed worksheets mostly individually, but at times with a partner. The teacher assisted the students and answered questions with limited interaction since most of the time was spent providing information to the students through lecture.

This study entails a pre/post design consisting of three phases: *Pre-Instruction*, *Instruction*, and *Post Instruction*. The pre-instruction phase consisted of students completing the demographic form, a STEM survey, and a critical thinking assessment. The instruction phase involved pre content knowledge assessments and instruction of STEM integrated content using TL and PBL approaches as discussed earlier. In PBL, special unit plans were designed that encompassed STEM integrated content embedded in problem-based scenarios. Whereas, the TL group was taught the same STEM integrated content via class lessons without the use of special unit plans. Finally, the post-instruction phase involved a post STEM survey along with post critical thinking and content knowledge assessments. For the PBL group only, a PBL questionnaire was also completed during the post instruction phase. The study design is outlined in (Figure 1) followed by an in-depth description of the instruments incorporated in this study. Additionally, the researcher conducted classroom observations every class session throughout the duration of the study. Field notes were taken during every observation except on assessment days.

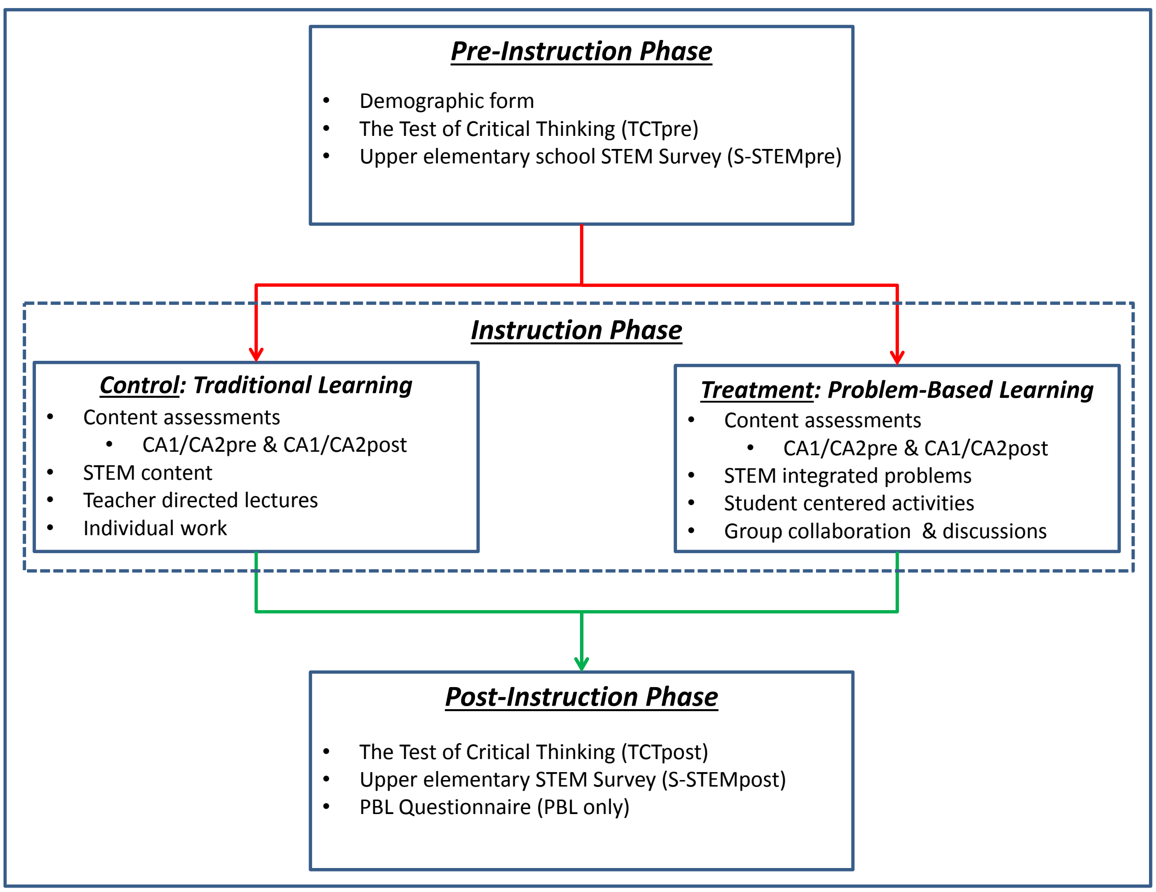

Figure 1. Pre/Post research study design basis.

PBL Unit Plans

Two STEM integrated problem-based units were developed for the treatment group (PBL). Both units were designed so that they would be appropriate for fourth grade students (Appendix F). Each of the unit plans addressed the *NGSS Standards* (Achieve, Inc., 2013), the *Nevada Common Core Mathematics Standards* and *Nevada Computer and Technology Standards* (Nevada Department of Education, 2012).

The first unit plan covered core disciplinary ideas in structure, function, habitat, and information processing. During the first problem scenario implementation (*Trout in the Classroom*), the students learned about the structures, functions, and habitat of a trout. The information gathered about the trout was used to design an aquarium habitat for the classroom. This aquarium was designed to mimic a trout habitat in which trout eggs were to be kept until they developed into a fry (Table 1).

In the second problem scenario, the core disciplinary ideas addressed were Earth’s systems and processes that shape the Earth. In this unit (*It’s a Bird, It's a Plane, it's a High-rise*) students learned about the geology of Nevada, plate tectonics, and possible natural disasters that can effect this region. After they understood the scientific core ideas, students used their understanding to design a luxury apartment high-rise for Caesars Entertainment that can withstand an earthquake (Table 2).

Table 1

NGSS Standards for PBL Unit 1

Students should be able to demonstrate an understanding that plants and animals that have internal and external stricture that function to support survival, growth behavior and reproduction.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
PS4-2 – Develop a model to describe a phenomena	LS1.A. Plants and animals that have internal and external stricture that function to support survival, growth behavior and reproduction.	LS1 & LS2 – A system can be described in terms of its components and their interactions.

Common Core State Mathematics Standards:
MP1: Make sense of problems and persevere in solving them.
MP3: Construct viable arguments and critique the reasoning of others.
4.MD.3: Apply area and perimeter formulas for rectangles in real world and mathematical problems
4.MD.6-2: Measure angles in whole- numbers degrees using a protractor. Sketch angles at specific measure.

State Computer and Technology Standards:
3.B.5.1: Use keywords to search, organize, locate, and synthesize information in multiple sources to create a product.
3.D.5.1: Collect, organize, analyze and manipulate data using digital tools and report results in a format appropriate to the task.
5.B.5.1: Use technology resource for problem solving, self-directed learning, and extended learning activities.

Table 2

NGSS Standards for PBL Unit 2

Students will be able to generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans and design solutions to engineering problems.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
4-ESS2-1: Make observations and/or measurements to produce data o serve as the basis for evidence for an explanation of a phenomenon.	ESS1.C: Global patterns of rock formations reveal changes over time due to earth forces, such as earthquakes.	4 ESS2-1 - Patterns can be used as evidence to support an explanation.
4ESS3-2: Generate and compare multiple solutions to a problem based on how well wee they meet the criteria and constraints of the design solution.	ESS2.B: Most earthquakes and volcanoes occur in bands that are often along the boundaries between continents and oceans.	E-SS2 -1 & 4 - ESS3-2 - Cause and effect relationships are routinely identified, tested, and used to explain change.
	ESS3.B: Natural hazards & a variety of hazards result from natural processes. Humans cannot take steps to reduce their impacts.	

Common Core State Mathematics Standards:
MP.2: Reason abstractly and quantitatively.
MP.4: Model with mathematics.
MP.5: Use appropriate tools strategically.
4.MD.3: Apply area and perimeter formulas for rectangles in real world and mathematical problems
4.MD.6-2: Measure angles in whole- numbers degrees using a protractor. Sketch angles at specific measure.

State Computer and Technology Standards:
3.B.5.1: Use keywords to search, organize, locate and synthesize information in multiple sources to create a product.
3.D.5.1: Collect, organize, analyze and manipulate data using digital tools and report results in a format appropriate to the task.
5. B.5.1: Use technology resource for problem solving, self-directed learning, and extended learning activities.

Content Knowledge Assessments

There were two content knowledge assessments (CA1 & CA2) created for this study, one for each unit (Appendix B). The questions on each of the content knowledge assessments comprised of multiple choice, true/false, and open-ended constructed response questions. There are approximately between 25 to 27 questions, with 3 to 5 constructed response items that covered science, math, engineering practices, and technology content areas.

For the first unit plan the assessment included science concepts, such as structure of a trout, functions of the trout's structure, life cycle, and habitat. In math content area, geometry concepts (rays and line segment relationships), symmetry, temperature, and measurements are addressed. While in engineering and technology, the test covers concepts in design, materials, and search tools. The first content assessment (CA1) has 27 questions in total; eighteen multiple choice, five true and false, and four short constructed response items. The total score students can attain on CA1 is 36 points.

In the second content assessment (CA2) questions cover land formations, plate tectonics, geology of Nevada, and natural disasters for science. In math, questions on measurements and word problems to calculate distance are included. Also the test comprises of engineering and technology questions on tools and practices. The second content knowledge assessment (CA2) has a total of 25 questions; seventeen multiple choice, five true/false, and three short answer questions. The total score students can attain on CA2 is 33 points.

A scoring rubric was created for the constructed response items (Appendix H). There were two types of content knowledge scores: 1) a score for the selected responses and 2) a score for the constructed responses. The two scores were then calculated to form a single composite score for each assessment. The constructed response items were scored blind to time and condition by two coders independently, and then the interrater reliability was determined. The interrater reliability ranged from 75 – 85%. Any disagreements between the coders' coding was discussed until an agreement was formed.

The Nevada Criterion Referenced Tests in math and science (CRT, Nevada Department of Education, 2013) laid the foundation for formulating the questions for these assessments. A panel of content experts established the content validity of the two content knowledge assessments. This panel included science educators and engineering professionals (i.e., university faculty, doctoral researchers, school administrators, and field engineers) along with various elementary teachers. In addition, the Cronbach's alpha coefficient was calculated using the Kuder Richardson (KR20) formula (Kuder & Richardson, 1937) to check the reliability of each instrument. Many researchers (Almehrizi, 2013; Cortina, 1993) suggest that it is "premature" (Yu, 2001, p. 23) to judge pretest scores of any instrument due to lack of treatment, because a low alpha may result (i.e., training in test content knowledge). Thus, the Cronbach's alpha coefficient was calculated for only posttest content knowledge assessments resulting in alpha coefficients of .80 (CA1) and .76 (CA2) indicating that the instruments were reliable.

The Test of Critical Thinking

The Test of Critical Thinking (TCT) created by Bracken, Bai, Fithian, Lamprecht, Little, and Quek, (2003) was utilized in this study (Appendix C). The test was specifically designed for elementary students focusing on grades 3 to 5 and is a reliable instrument to use for gifted and general education student populations. The TCT is theoretically based on Facione (1990) Delphi panel's definition of critical thinking and covers six core skills. These skills include: interpretation, analysis, evaluation, inference, explanation, and self-regulation. The TCT comprises of 45 items arranged across ten scenarios. After each scenario there are three to six multiple-choice items. The scenarios in the TCT address seven important life domains: social, affect, competence, environmental, family, physical, and academic. Since the test is intended to assess critical thinking skills, not reading comprehension, the overall reading level of the TCT is near the lower end of the target population (i.e., third grade). The total possible score on the TCT is 45 points.

The content validity of the test of critical thinking (TCT) as reported in the administration guide was established through project Athena, a curriculum intervention study assessing verbal critical thinking skills. The Cronbach's alpha of the TCT was .89 for the total population and each grade level group's internal consistency ranged from .83 to .87 (VanTassel-Baska, Bracken, Feng, & Brown, 2009).

Upper Elementary School S-STEM Survey

The upper elementary attitude S-STEM survey developed by the Friday Institute for Educational Innovation (2012) was employed to measure fourth grade students' attitude towards STEM in this study (Appendix D). This instrument consists of 37 statements; eight attitudes toward math, nine attitudes toward science, nine attitudes toward engineering and technology, and eleven attitudes toward 21st century skills. Participants responded to these items on a five-point Likert scale (i.e., strongly agree, agree, neither agree or disagree, disagree, and strongly disagree) with a score of 1 representing negative attitudes towards STEM while a score of 5 representing a positive attitude. Possible scores for the S-STEM survey range from 37 – 185 points.

The content validity of the S-STEM survey was reported as being established by a committee of five content experts and ten upper elementary teachers. Also, an exploratory factor analysis was conducted, applying principal axis factoring and promax rotation to allow factors to be correlated. Item loadings above .40 were classified as significant. In addition, the final S-STEM survey was piloted to 799 fourth through fifth grade students. The results indicated a clear factor structure and the constructs' reliability level measured with a Cronbach's alpha of 0.85. Since the survey was recently created, there is no further reported data available on test reliability and validity.

PBL Questionnaire

After the participants completed the instruments of the study (CA1, CA2, TCT, and S-STEM), only the PBL group was asked to complete the PBL questionnaire. The open-ended questionnaire consists of five questions designed to probe students to share their experiences of the problem-based learning environment. The students were given the opportunity to address their likes and dislikes regarding science and math learning through PBL and describe the strategies they used to solve each problem scenario (Appendix E). The PBL questions were influenced from the study conducted by Tarhan et al. (2007).

Classroom Observation

Classroom observations were conducted with field notes taken throughout the duration of the study. Observations took take place in both the problem-based learning environment as well the traditional learning environment, which included the teacher and the students. Classroom observations were made for every class session with detailed field notes taken during each observation except on assessment days. The teacher was observed for: the classroom environment created for each group's instruction, implementation of the unit plans, and her role in each learning environment. The students' were observed to determine how they interacted with their peers within and outside of their assigned teams as well as how they interacted with the teacher during the unit activities. The researcher in this study played the role of a participant researcher in the PBL group and observer in the TL group. The researcher along with the teacher facilitated the activities and engaged in discussion with students without fully committing oneself to members' values and goals in the PBL group (Merriam, 2009).

Procedures

The study commenced once the university and school IRB was approved. Given that all participating fourth graders had science once a week for 55 minutes, the duration of this study was approximately 17 weeks. As outlined earlier, two classes were randomly assigned to the PBL group while the other two classes to the TL group. As mentioned above, class 1 of the TL group had science on Mondays and class 2 of the TL group on Tuesdays. For the PBL group, class 3 had science on Wednesdays and class 4 on Thursdays. The study was divided into three phases: *Pre-Instruction Phase*, *Instruction Phase*, and *Post Instruction Phase* (Table 3). A detailed explanation of the procedures during each phase is provided below.

Table 3

Study Implementation Timeline for Treatment (PBL) and Control (TL) Group

Activity	Duration
Pre-Instruction Phase • Assent form • Demographic form • The Critical Thinking Test (TCT) • Upper elementary school S-STEM survey (S-STEM)	Two class periods (2 weeks – 110 minutes)
Instruction Phase – Unit Plan 1 • Pre Content Assessment 1 (Trout in the Classroom) • Problem presentation, students' identification of the problem to be investigated. • Self-regulated investigation, data organization, and design • Sharing findings. • Control group: Normal instruction guided by lessons • Post Content Assessment 1 (Trout in the Classroom)	Six class periods (6 weeks – 330 minutes)
Instruction Phase – Unit Plan 2 • Pre Content Assessment 2 (It's a Bird, It's a Plane, it's a High-rise) • Problem presentation, students' identification of the problem to be investigated. • Self-regulated investigation, data organization,, and design • Sharing findings. • Control group: Normal instruction guided by lessons • Post Content Assessment 2 (It's a Bird, It's a Plane, it's a High-rise) •	Six class periods (6 weeks – 330 minutes)
Post- Instruction Phase • The Critical Thinking Test (TCT) • Upper elementary school S-STEM survey (S-STEM) • PBL questionnaire (Treatment Group)	Three class periods (3 weeks-110 minutes)

Pre-Instruction Phase

The pre-instruction phase initiated once the students completed the student assent forms and returned the parental consent forms that authorized them to participate in the research. After all forms were received, the students in both groups (TL & PBL) that agreed to participate in the study were asked to complete a demographics form. Additionally, the participants in both groups completed the S-STEM survey (S-STEMpre) and the Critical Thinking Test (TCTpre).

Instruction Phase

The instruction phase began with both groups (TL & PBL) completing content knowledge assessment 1 (CA1pre) for activity 1, week 1 of the instruction phase. This assessment was taken during week 3 of the overall study. Once this was complete, both groups were then provided instruction according to their assigned groups. Prior to beginning the second unit plan or lesson, both groups again completed a content knowledge assessment (CA2pre) before continuing with their respective instruction.

Treatment group (PBL). The participants in the treatment group were randomly divided into teams of about five to six students per team. This was followed by implementation of the first PBL unit allocated into five stages as identified by Gallagher et al. (1995): (1) problem presentation, (2) students' identification of the problem to be investigated, (3) self-regulated investigation, (4) data organization, and (5) sharing their findings.

In the first stage, the teacher introduced the ill-structured problem to the students. She gave the students two minutes to individually re-read, reflect, and take notes in their science notebook regarding the problem. This led to the second stage during which students discussed their ideas within their teams, collaborated to form a complied set of ideas, and recorded them on the *Need to Know Worksheet* (Appendix G) together as a team. The worksheet started with the question, “What do you know?” The second question was, “What do you need to know? Finally, the last question, “How can you find out what you need to know?” As soon as all the teams had compiled their ideas together, a class discussion was held with the teacher regarding the current problem. The teacher went through each column of the *Need to Know* worksheet and recorded each team’s responses on the white board (Table 4 & Table 5). The need to know worksheet helped to guide the learning and served as an organization tool for the students.

Table 4

Student Brainstorm Session During PBL Unit Plan 1

What do you know?	*What do you need to know?*	*How will we find out?*
Big Bodies	What is a fry	Internet Research
100 Eggs	How long does it take to grow	Books
Eggs are small	What type of water / lake water	Ask other people
Need Water	What should the temperature of the water be?	Dictionary
Eat worms		
Predator is bigger fish		
We have to build and aquarium		
Measure height and width of the table		

Table 5

Student Brainstorm Session During PBL Unit Plan 2

What do you know?	*What do you need to know?*	*How will we find out?*
We have to make a high-rise	What kind of budget we have?	Internet Research
High-rise is a tall building	What kind of materials we should use?	Books
It needs to withstand disasters	What causes naturals disasters such as earthquakes in Nevada?	Ask other people
The materials should be strong and sturdy	What should be the dimensions of the building?	Dictionary
Natural disasters can be deadly		Articles
As Nevadans we need to be prepared for natural disasters such as earthquakes, wildfires and floods.		

During the third stage, students conducted research, discussed the problem within their teams, and took notes in their science notebooks. In addition to their science textbooks, the teacher had books available for the students to gather information pertaining to each unit plan. The students had computers available for them to use and some suggested websites were also provided for each unit plan. The teacher during this stage actively facilitated the learning and monitored students' progress. The whole process of gathering information took an entire class period.

In the fourth stage, the team members first compiled and organized the information or data that they had collected. This was followed by each team conceptualizing their prototype then designing, and testing their prototype. The students were told to use consumable materials (i.e., plastic totes, straws, plastic disposable water bottles, rock or other earth materials, various materials for insulation purposes, other consumable materials, accessible testing instruments, and children's building toys), which were available for them in class and did not pose a safety hazard. They had to identify what each material represented and the property of each material during their presentation (i.e. plastic box represents a certain type of glass for the aquarium). For the trout activity, consumable materials were used to build the aquarium and for the high-rise activity, Legos® were used to build the high rise. This stage of the instruction phase took approximately one and a half class periods to complete.

Finally, in the fifth stage, each team had to give a 7 – 10 minutes detailed presentation to the entire class where they shared their model, identified the materials they utilized for their prototype, and their solution to the problem. For the high-rise activity, during the presentation, the teams had to simulate an earthquake shake test to demonstrate the building's ability to withstand a possible earthquake. Once every team had presented, the entire class then reflected on the problem and discussed each team's prototype or model.

The two unit plans for the PBL group followed the same procedures with a completion time of four weeks for each unit. During the sixth week of each unit, students completed the post content knowledge assessments. A breakdown of the 6 weeks allotted to the instruction phase in the PBL group is shown in (Table 6)

Table 6

Timeline of Instruction Phase Implementation for Treatment (PBL) Group

Timeline	PBL Group Procedure
Instruction Phase *Week #1*	Pre Content Assessments • *Unit Plan 1*: CA1pre – Trout in the Classroom • *Unit Plan 2*: CA2pre – It's a Bird, it's a Plane, it's a High-rise
Instruction Phase *Week #2*	Stage 1 & 2: Problem Presentation / NKW Chart • *Unit Plan 1*: Trout Habitat • *Unit Plan 2*: Natural Disaster
Instruction Phase *Week #3*	Stage 3: Research and Gather Data • *Unit Plan 1*: Trout Habitat & Aquarium • *Unit Plan 2*: Natural Disaster & High-rise
Instruction Phase *Week #4*	Stage 4: Design and Testing • *Unit Plan 1*: Build aquarium for Trout eggs. • *Unit Plan 2*: Build high-rise building resistant to earthquake
Instruction Phase *Week #5*	Stage 4: Design and Testing (Continued) Stage 5: Group Presentations
Instruction Phase *Week #6*	Post Content Assessment • *Unit Plan 1*: CA1 • *Unit Plan 2*: CA2

Note: Since the classes met once a week, the first two weeks, students in the PBL group completed the Demographic form, S-STEMpre, and TCTpre. Next, students completed unit plan 1 for 6 weeks (including CA1post), followed by unit plan 2 for 6 weeks (including CA2post). Lastly, they completed TCTpost, S-STEMpost survey & PBL questionnaire during the last three weeks (Total weeks = 17).

Control group (TL). The TL group's instruction varied from the PBL group as outlined earlier. The TL group used instructional materials such as their *Scott Foresman Science* textbook (Cooney, DiSpezio, Foots, Matamoros, Nyquist, & Ostlund, 2000) along with supplemental materials incorporated by the teacher to utilize with each lesson. The teacher conducted the class normally using PowerPoint slide shows to present the lesson material. For the second and third week of each lesson, the teacher lectured using PowerPoint slide shows for one and a half class periods, while the students took notes in their science notebook. Also, during the third week of each lesson, the students watched a video associated with each lesson topic and completed a worksheet. The teacher went over the worksheet with the students prior to the end of the class period. During week four, students completed a comprehensive work packet associated with each lesson. The work packet included contents in science, math (taken directly out of the textbook), and engineering design worksheets. The work packet was designed to reinforce concepts covered during weeks two and three of each lesson. While the students completed the work packets, the teacher was available to answer any questions posed by the students. Finally, during week five, the students were allotted 30 minutes to complete the work packet prior to reviewing and answering students' questions during the second half of the class period. The length of each lesson for the control group was also four weeks long with the sixth week allotted to completing the post content knowledge assessment for each lesson. A breakdown of the 6 weeks allotted to the instruction phase in the TL group is shown in (Table 7)

Table 7

Timeline of Instruction Phase Implementation for Control (TL) Group

Timeline	TL Group Procedure
Instruction Phase *Week #1*	Pre Content Assessments • *Lesson 1*: CA1pre – Trout in the Classroom • *Lesson 2*: CA2pre – It's a Bird, it's a Plane, it's a High-rise
Instruction Phase *Week #2*	Lecture: PowerPoint Slide-show • *Lesson 1*: Trout habitat/life cycle • *Lesson 2*: Earth's processes
Instruction Phase *Week #3*	Lecture: PowerPoint Slide-show (continued) • *Lesson 1*: Trout body structure and function • *Lesson 2*: Natural disasters Video & Worksheet • *Lesson 1*: o "The Brook of Life" video o Worksheet on trout structures and functions • *Lesson 2*: o "The Natural Disasters" video o Worksheet on various natural disasters
Instruction Phase *Week #4*	Work Packets • *Lesson 1*: o Trout habitat and life cycle (science and math) o Aquarium design sheet • *Lesson 2*: o Earth processes and earthquakes (math and science) o Building a high rise
Instruction Phase *Week #5*	Work Packets (Continued) Review of Activity Material • *Lesson 1*: Trout habitat/life cycle • *Lesson 2*: Earth's processes
Instruction Phase *Week #6*	Post Content Assessment • *Lesson 1*: CA1 • *Lesson 2*: CA2

Note: Since the classes met once a week, the first two weeks, students in the TL group completed the Demographic form, S-STEMpre, and TCTpre. Next, students completed lesson 1 for 6 weeks (including CA1post), followed by lesson 2 for 6 weeks (including CA2post). Lastly, they completed TCTpost, and S-STEMpost survey, that took two weeks (Total weeks = 16).

Post Instruction Phase

The post instruction phase started once both unit plans (PBL) and activities (TL) and content knowledge assessments (CA1post & CA2post) had been completed. During the post instruction phase, students in the TL and PBL groups took the S-STEM survey (S-STEMpost) and the test of critical thinking (TCTpost) during weeks 15 and 16. Lastly, only the students in the PBL group completed the PBL questionnaire during week 17.

CHAPTER 5

RESULTS AND ANALYSES

Quantitative and qualitative analyses with outcomes associated with the four research questions of this study will be presented in this Chapter. As outlined in Chapter 1, the quantitative research questions will measure the impact of PBL on fourth grade students' STEM content knowledge, critical thinking skills, and their attitude towards STEM education. Similarly, the qualitative question explored fourth grade students' STEM integrated PBL experience after implementation. The demographics of the sample population will be discussed initially, followed by a description of each analysis conducted for the data types. Finally, the outcomes of the quantitative and qualitative data will be provided.

Descriptive Data

The study analysis initiated with descriptive statistics conducted on the demographic form to illustrate a general overview of the subjects as outlined in Chapter 4. Out of 105 fourth grade students in the school a total of 98 fourth graders (n = 98) fully participated in this study. The term "fully participated" is defined as those students that provided parental consent and self-assent, were present for the study activities, and completed all of the study instruments.

The participants' demographics (Table 8) reflected the population of their school, which is located in a large suburban school district of predominately White/Caucasian ethnicity. From the total sample population, forty-eight were males (n_{males} = 48) and fifty were females ($n_{females}$ = 50). The group population included a total of fifty-two participants in the PBL group ($n_{Treatment}$ = 52) with forty-six in the TL group ($n_{Control}$ = 46). There was one science teacher involved in this research that taught all fourth grade classes. She was the science specialist for the school.

Table 8

Demographic Data for Sample Participants

Ethnicity	*n*	*Percent*
American Indian/Native American	3	3%
Black/African American	4	4%
Asian/Pacific Islander	8	8%
Hispanic/Latino	7	7%
White/Caucasian	76	78%
Total	98	100%

Quantitative Analysis

A quantitative analysis was conducted for the first three research questions. These questions involved mixed repeated measure between-within subject analysis of variance (ANOVA). The independent groups were problem-based learning (PBL) and traditional learning (TL), which is a categorical independent between-subjects variable with time (Pre and Post) as the two levels, also a categorical independent within-subjects variable. The continuous dependent variables were scores on the two content knowledge assessments (CA1 & CA2), the critical thinking test (TCT), and a STEM attitude survey

(S-STEM) measured at each time period (pre/post). For the purpose of clearly reporting the quantitative results, the group that engaged in STEM through PBL method or the treatment group will be referred to as the PBL group and the group that engaged through teacher-centered method or control group will be referred to as traditional learning group or TL group. The progression of the quantitative analysis is shown in (Figure 2).

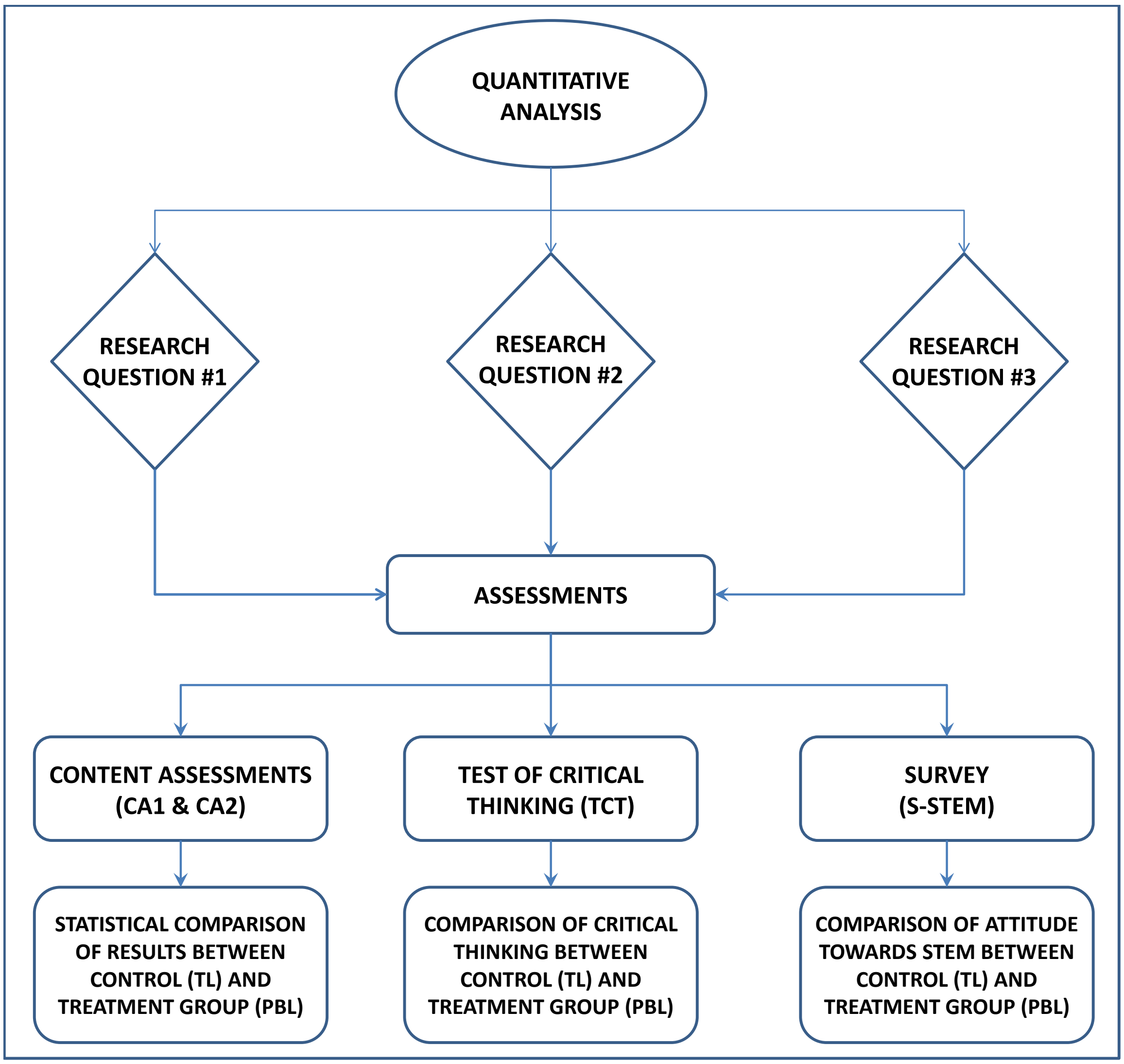

Figure 2. Quantitative analysis of STEM integration in TL and PBL

The quantitative results are presented in order of the quantitative research questions for this study.

1. What is the impact of problem-based learning as compared to traditional learning on fourth grade students' STEM content knowledge?
2. What is the impact of problem-based learning as compared to traditional learning on fourth grade students' critical thinking skills?
3. What is the impact of problem-based learning as compared to traditional learning on fourth grade students' attitude towards STEM education?

Assumptions Testing

In order to address research questions 1, 2, and 3, a mixed repeated measure approach between-within subject analysis of variance (ANOVA) was executed. The study analysis was initiated by first examining the assumptions of a mixed repeated measures ANOVA design.

The first inspection tested for the assumption of normality for all dependent variables. Morgan and Griego (1998), state that if the skewness and/or kurtosis statics is greater than 2.5 times the respective standard error, then the assumption of normality is violated. Alternatively, it is suggested that if the skewness or kurtosis statics has an absolute value greater than 2, then the distribution is considered non-normal (Hinkle, Wiersma & Jurs, 2003; Keppel & Wickens, 2004). Given these considerations, the assumption of normality for the dependent variables was met. Next, Levene's Test of Equality of Error Variances was used to examine the assumption of homogeneity of variances for each variable. Since the values were non-significant (greater than .05), this assumption was met as well. Lastly, this study also met the assumption of equality of covariance matrices considering Box's Test of Equality of Covariance Matrices yielded non-significant results (greater than .001) (Keppel & Wickens, 2004). Considering this study is a 2 x 2 repeated measure design, the assumption of sphericity should not be considered. According to Keppel and Wickens (2004), sphericity is the symmetrical difference between pairs of scores; this assumption only applies if there are more than two levels of independent variables. For this study, the alpha value of .05 was used to test any significant gains. Also, to determine the effect size, Cohen's (1988) guidelines for partial eta squares (.01≥ small effect, .06 ≥ medium effect, .13 ≥ large effect), were applied.

After all the assumptions were upheld, pre analysis using a one-way ANOVA was performed on the pre-dependent variables (CA1pre, CA2pre, TCTpre, & S-STEMpre). This was done to determine if any differences existed between the two groups prior to intervention. The outcomes (Table 9) indicated that all groups were initially equal or no significant difference existed between the groups ($p > .05$).

Table 9

One-way ANOVA Table for Group Differences on Pre-Assessments

Source	*SS*	*df*	*MS*	*F*	*p*
One-way ANOVA for Content Assessment (CA1pre)					
Between Groups	4.438	1	4.438	1.211	.274
Within Groups	351.970	96	3.666		
Total	356.408	97			
One-way ANOVA for Content Assessment (CA2pre)					
Between Groups	4.632	1	4.632	.882	.350
Within Groups	503.899	96	5.249		
Total		97			
One-way ANOVA for Test of Critical Thinking (TCTpre)					
Between Groups	.789	1	.789	.093	.761
Within Groups	815.130	96	8.491		
Total	815.918	97			
One-way ANOVA for S-STEM Survey (S-STEM pre)					
Between Groups	32.402	1	32.402	.138	.711
Within Groups	22547.935	96	234.874		
Total	22580.337	97	22580.337		

Quantitative Results

The first research question inspected the impact of PBL on students' STEM content knowledge (see Appendix B). The first content knowledge assessment (CA1) contained a total of 27 questions, while the second content knowledge assessment (CA2) contained a total of 25 questions.

Content Knowledge Findings

A mixed repeated measures analysis of variance was conducted for both of the content knowledge assessments to investigate the impact of the teaching method (PBL vs.

TL) on students' scores on the content knowledge assessments across two time periods (CA1pre – CA1post & CA2pre – CA2post). The data analysis of CA1 and CA2 revealed an increase in students' mean scores from pretest to posttest in both PBL group and TL group (Table 10). For CA1, the PBL group's average mean score increased from 11.73 to 26.54 showing a gain of 14.81; whereas the TL group's average increased from 11.30 to 23.43, an improvement of 12.13. On CA2 the PBL group's average mean score increased from 9.67 to 22.81 showing an improvement of 13.14, while the TL group's average mean score improved from 10.11 to 18.07 showing an increase of 7.96 on CA2.

Table 10

Pre/Post Content Knowledge Assessment Scores for TL and PBL Groups

	Pretest		Posttest	
Groups	*M*	*SD*	*M*	*SD*
		CA1		
TL	11.30	1.82	23.43	3.11
PBL	11.73	2.00	26.54	2.60
		CA2		
TL	10.11	1.87	18.07	3.04
PBL	9.67	2.61	22.81	3.21

$n_{Control} = 46$; $n_{Treatment} = 52$

The statistical analysis for CA1 provided evidence that the interaction between time and teaching method was statistically significant, Wilks' $\lambda = .85$, $F\ (1, 96) = 16.88$, $p < .001$, $\eta_p^2 = .15$. There was a substantial main effect for time, Wilks' $\lambda = .05$, $F\ (1, 96) = 1708.40$, $p < .001$, $\eta_p^2 = .95$, with both groups (PBL & TL) showing an increase in CA1 scores across the two time periods. The main effect comparing the two types of teaching methods was also significant, $F\ (1, 96) = 22.94$, $p < .001$, $\eta_p^2 = .19$, (large effect size) suggesting a difference in the effectiveness of the two teaching methods (Figure 3) on students' content knowledge assessment (CA1).

Similarly, the statistical analysis for CA2 provided evidence that the interaction between time and teaching method was statistically significant, Wilks' $\lambda = .63$, $F\ (1, 96) = 57.33$, $p < .001$, $\eta_p^2 = .37$. There was also a large main effect for time, Wilks' $\lambda = .09$, $F\ (1, 96) = 951.10$, $p < .001$, $\eta_p^2 = .91$, with both groups (PBL & TL) showing a rise in CA2 scores across the two time periods. The main effect comparing the two types of teaching methods was also significant, $F\ (1, 96) = 24.29$, $p = .02$, $\eta_p^2 = .20$, (large effect size) suggesting a difference in the effectiveness of the two teaching methods (Figure 4) on students' content knowledge assessment (CA2).

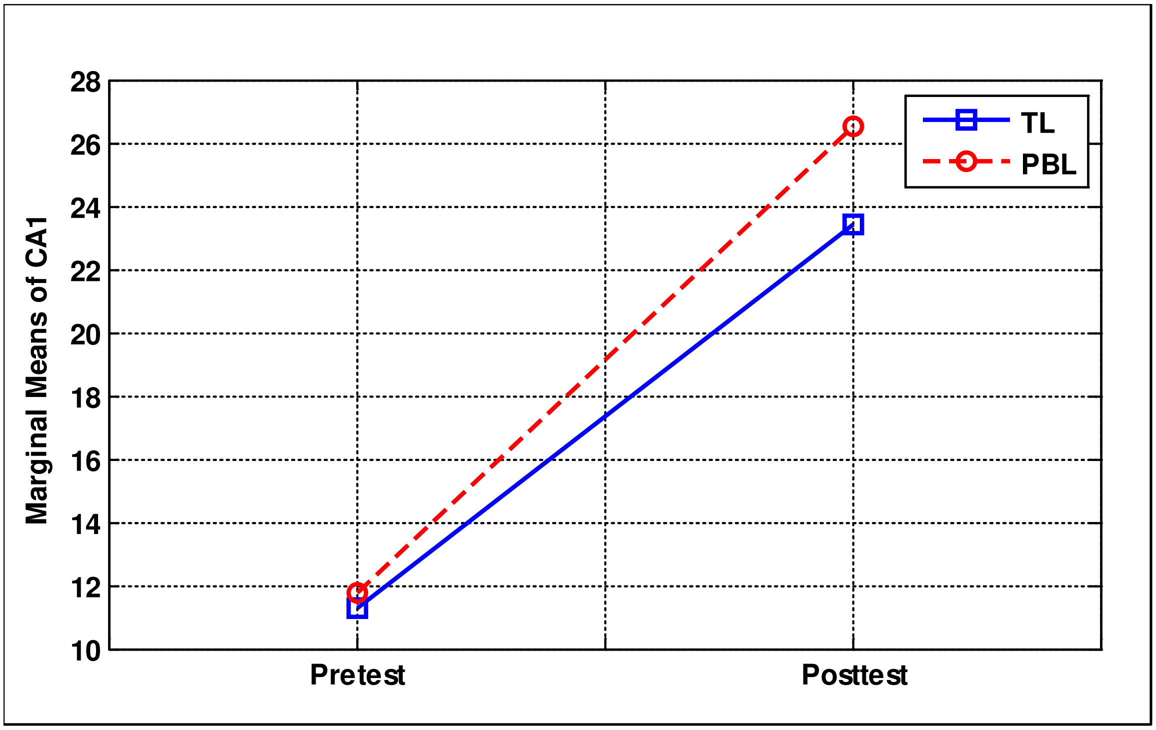

Figure 3. Change in students' content knowledge, CA1, for TL and PBL groups.

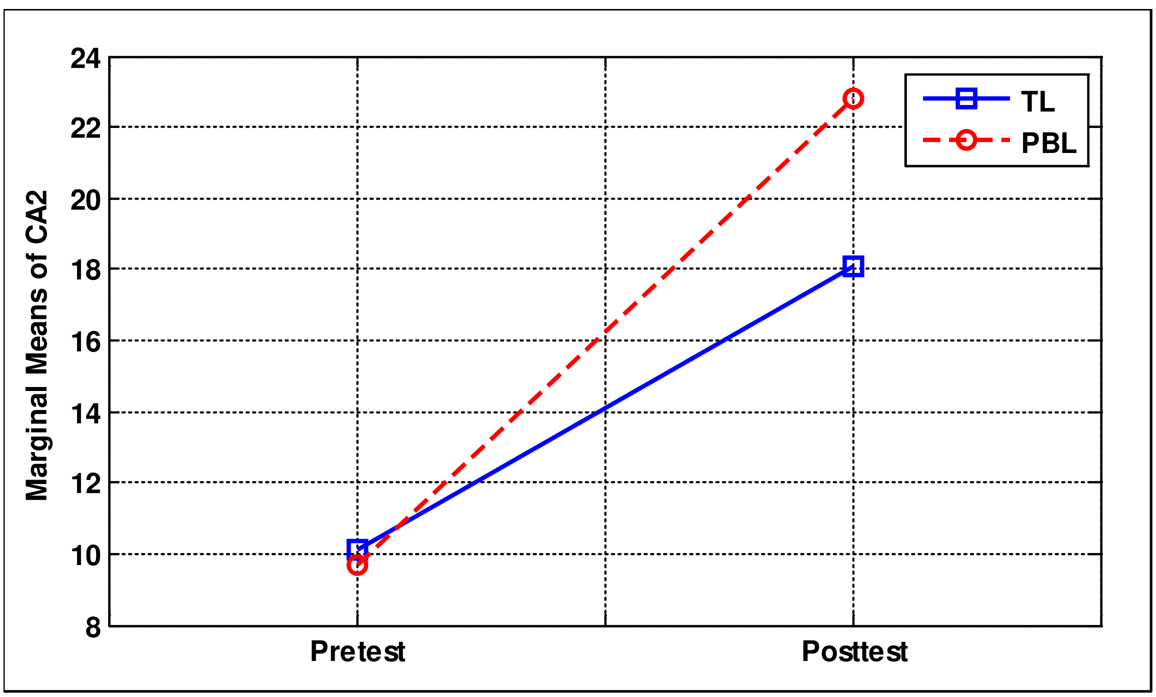

Figure 4. Change in students' content knowledge, CA2, for TL and PBL groups.

As hypothesized, the findings from both STEM content knowledge assessments (CA1 & CA2) indicate that the fourth grade students that participated in the PBL group showed improvements on their STEM content knowledge assessments as compared to those that participated in TL group. The main effect comparing the two types of teaching methods in both STEM content knowledge assessments was large (Cohen, 1988), indicating a significant difference between teaching method and time.

Critical Thinking Findings

The second research question investigated the impact of PBL on students' critical thinking skills. Analysis from the 45 question test of critical thinking pretest and posttest data (TCTpre & TCTpost, see Appendix C) showed that the mean scores of students in the both PBL group and TL group increased from pretest to posttest (Table 11). The PBL group's average scores over the course of study increased from 16.29 to 37.19 showing a gain of 20.90 on the TCT; whereas, the TL group's average increased from 16.11 to 21.37 with a gain of 5.26.

Table 11

Pre/Post Test of Critical Thinking Scores for TL and PBL Groups

	Pretest TCT			Posttest TCT	
Groups	*N*	*M*	*SD*	*M*	*SD*
TL	46	16.11	3.34	21.37	6.12
PBL	52	16.29	2.48	37.19	5.03
Total	98	16.20	2.90	29.77	9.68

A mixed repeated measures analysis of variance was conducted to assess the impact of teaching method (PBL & TL) on students' scores on the TCT across two time periods (pre & post). The statistical analysis provided evidence that the interaction between time and teaching method was statistically significant, Wilks' $\lambda = .34$, $F\,(1, 96) = 190.66$, $p < .001$, $\eta_p^2 = .67$. There was a substantial main effect for time, Wilks' $\lambda = .85$, $F\,(1, 96) = 533.39$, $p < .001$, $\eta_p^2 = .88$, with both groups (PBL & TL) showing an increase in TCT scores across the two time periods. The main effect comparing the two types of teaching methods was also significant, $F\,(1, 96) = 131.23$, $p < .001$, $\eta_p^2 = .58$, (Cohen, 1988) suggesting a significant difference in the effectiveness of the two teaching methods on students' critical thinking skills (Figure 5).

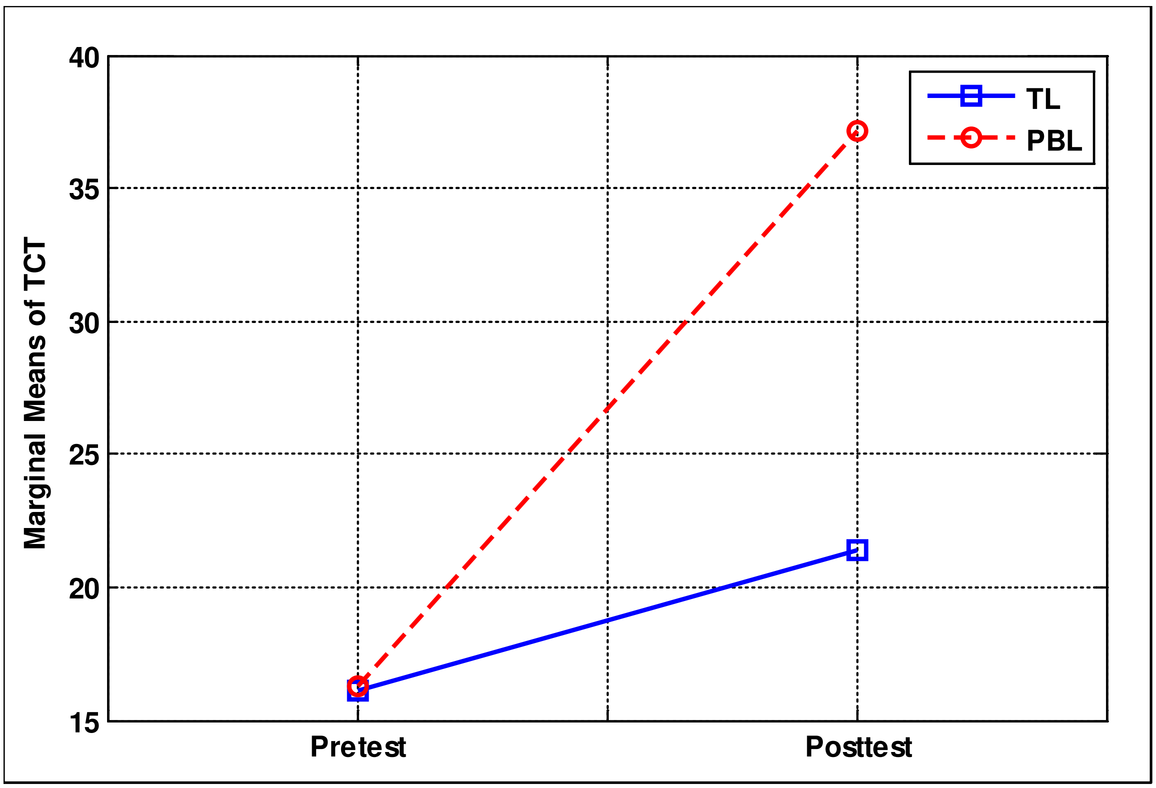

Figure 5. Change in student's critical thinking for TL and PBL groups.

Consequently as hypothesized, fourth grade students that participated in the PBL group showed greater gains in their critical thinking skills as compared to those that participated in TL group.

STEM Attitude Findings

The third research question examined the effect of PBL on fourth grade students' attitude towards STEM education. The initial examination of the 37 questions S-STEM attitude survey data (Appendix D) revealed an increase in the mean scores of the PBL and TL groups from pretest to posttest (Table 12). The PBL group's average scores over the course of study improved from 135.00 to 155.98 showing a gain of 20.98 on the S-STEM attitude survey; whereas, the TL group's average improved from 136.15 to 142.61, a gain of 6.46.

Table 12

Pre/Post S-STEM Survey Scores for TL and PBL Groups

	Pretest S-STEM			Posttest S-STEM	
Groups	*N*	*M*	*SD*	*M*	*SD*
TL	46	136.15	15.498	142.61	15.945
PBL	52	135.00	15.172	155.98	16.998
Total	98	135.54	15.257	149.70	17.744

A mixed repeated measures analysis of variance was conducted to inspect any difference between the TL and PBL groups regarding their attitude towards STEM. The statistical analysis provided evidence that the interaction between time (pre & post) and teaching method (TL & PBL) was statistically significant, Wilks' $\lambda = .92$, $F(1, 96) = 8.211$, $p < .005$, $\eta_p^2 = .10$. There was a medium main effect for time, Wilks' $\lambda = .77$, $F(1, 96) = 29.30$, $p < .001$, $\eta_p^2 = .23$, with both groups (PBL & TL) showing an increase in S-STEM attitude scores across the two time periods. The main effect comparing the two groups (PBL & TL) was also significant, $F(1, 96) = 9.394$, $p = .03$, $\eta_p^2 = .09$, (Cohen, 1988) suggesting a significant difference in the effectiveness of improving students' attitude towards STEM education between the two instructional methods (Figure 6).

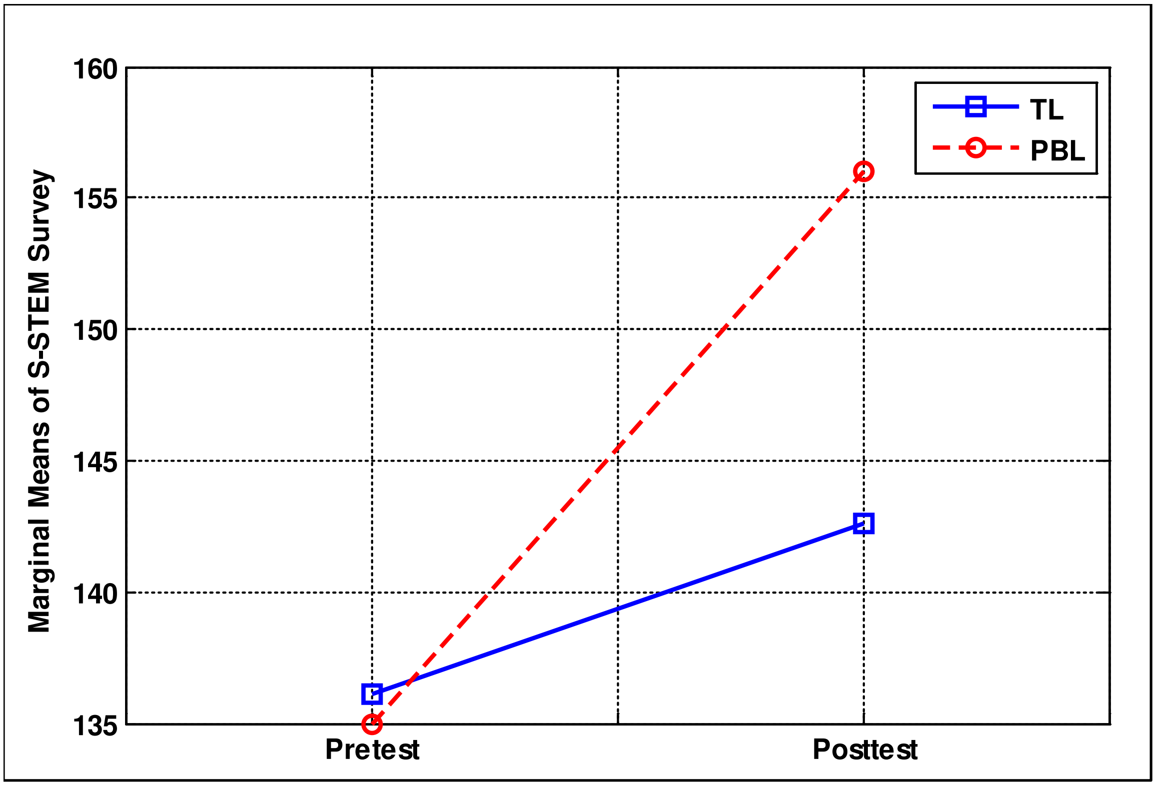

Figure 6. Change in students' STEM attitudes for TL and PBL groups.

The participants in both groups displayed positive attitudes towards STEM over the course of the study. This finding supports the hypothesis that fourth grade students' attitude towards STEM in the PBL group was substantially impacted as compared to those that participated in the TL group.

Further investigation of the individual items on the post STEM survey (S-STEM) was conducted to assess the cause of the significant difference between the treatment PBL and TL group's attitude towards STEM. The descriptive statistics revealed that responses to ten items on the STEM survey (S-STEM) could have contributed to the differences in attitude towards STEM between the PBL and TL group. The items along with the percentages are presented below (Table 13).

Table 13

Percentage Differences of S-STEM Survey Questions for TL to PBL Group

Questions From S-STEM Attitude Survey	Control Group (TL)		Treatment Group (PBL)	
	Agree	**Disagree**	**Agree**	**Disagree**
2. I would consider choosing a career that uses math.	48%	22%	*89%*	*7%*
10. I would consider a career in science.	54%	24%	*56%*	*6%*
11. I expect to use science when I get out of school.	59%	20%	*87%*	*4%*
13. I will need science for my future work.	65%	21%	*72%*	*0%*
21. I am interested in what makes machines work.	80%	9%	*85%*	*2%*
22. Designing products or structures will be important for my future work.	67%	11%	*96%*	*0*
23. I am curious about how electronics works.	78%	4%	*96%*	*4%*
24. I would like to use creativity and innovation in my future work.	85%	0%	*96%*	*4%*
25. Knowing how to use math and science together will allow me to invent useful things.	72%	7%	*98%*	*2%*
26. I believe I can be successful in a career in engineering.	61%	17%	*98%*	*2%*

Note: 'Agree' is the sum of agree and strongly agree; 'Disagree' is the sum of disagree and strongly disagree. The unaccounted percentages are for those that stayed neutral.

Qualitative Analysis

The final question explored students' problem-based learning experience comprised of analyzing an open-ended post problem-based learning questionnaire (PBL questionnaire, Appendix E). Also, field notes gathered from the classroom observations were analyzed qualitatively. A qualitative phenomenological design was employed for the analysis. This design method was used since the students' in the PBL group all shared and experienced a common phenomenon of the problem-based learning enriched environment during the study duration (Litchman, 2010). The validity of this research can be verified with the multiple data sources. The objective of incorporating a qualitative analysis in this research was to strengthen the research by providing internal validity through triangulation (Creswell, 2007).

A content analysis was performed on the open-ended questions and class observation field notes (Figure 7). The collected data was coded by two researchers and analyzed for themes (Merriam, 2009). Initial agreement between the two researchers was 76%. Any disagreements between the researchers' coding was discussed until a mutual agreement was reached. This whole process is continuous and one that builds on itself. The initial themes that emerged were revised and then grouped under larger over-arching themes. These over-arching themes eventually led to answering the final research question and provided an explanation for the quantitative data. For clarity purposes, the following abbreviated identifiers are used when quoting from the data: 'S#" for student identification and 'FN' for field notes from classroom observations. Similarly, to avoid confusion, each data entry is dated for proper identification.

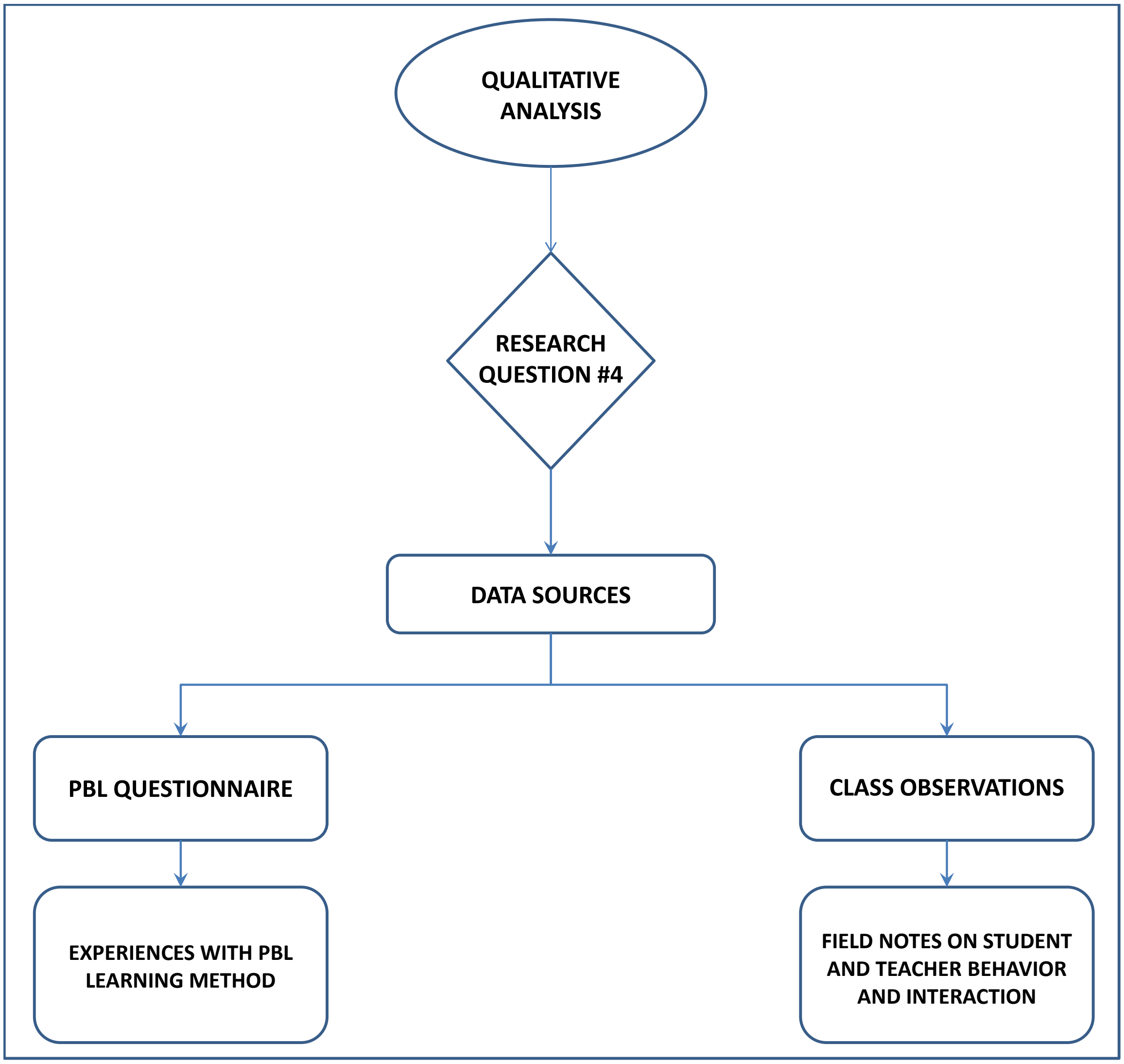

Figure 7. Qualitative analysis of STEM integration in PBL

Qualitative Results

Three major themes emerged from the coded data based on the following research question, "How will students describe their STEM integrated problem-based learning experience after implementation"? The themes were as follows: *learning approaches*, *increased interaction*, and *design and engineering*. An example of learning approach refers to the various methods employed by students to solve PBL problems. Increased interaction refers to the overall PBL environment in terms of the student and teacher interaction. Finally, design and engineering refers to the STEM integrated PBL environment.

Learning Approaches

The qualitative data corroborated the finding from the quantitative data and provided more elaborate information about what the students' experienced and the approaches they employed as they solved the problems in this new PBL environment. The field notes from classroom observations along with students' responses to the PBL questionnaire demonstrated how students' used their prior knowledge in science and math to help them design an aquarium for the trout as well as earthquake resistant high-rise building. During the problem presentation stage, students held discussions in their groups and brainstormed many facts about the trout and natural disasters that they already knew. This assisted them in collecting necessary information they needed to solve the problems. Examples of facts about the trout mentioned by students included "trout is a type of fish [and] trout live in fresh water" (FN, 1/28/15). While facts related to natural disasters and high-rise comprised of "a high rise is a tall building [and an] earthquake is a common natural disaster in Nevada" (FN, 3/9/15). Furthermore, one student mentioned, "I used facts about the life cycle of [a] trout to figure out their natural habitat and used math calculations to figure out the dimensions of the aquarium (S# 14483, 5/27/15). Additionally, another student stated, "I know that a trout can grow pretty long like 30 cm then you would think [*sic*] how big the tank should be" (S# 14450, 5/27/15). Similarly, another student indicated that he used "math to count how many trout eggs are coming and will fit in the aquarium" (S# 14452, 5/28/15) to aid him in determining the right measurement for the aquarium. In regards to the high-rise problem, a student claimed they "used science and engineering to find out how to make the building stable and math to calculate the height and width of building" (S# 14494, 5/27/15).

Additionally, students' described that in the PBL environment they were able to use technology and conduct research to gather information, which enabled them to solve the two problem scenarios. A student stated for the first problem scenario, "I used a computer, which is science by looking into how the trout swims and hunts"(S# 14494, 5/27/15). While another student mentioned, "I used science to research the temperature they [trout] are used to. Plus what kind of body structure they have" (S# 14478, 5/27/15). For the second problem scenario, several students mentioned they researched information about Nevada, natural disasters, and plate tectonics. As one student indicated that he researched earthquakes and how a high-rise building can survive one" (S# 14488, 5/28/15). Likewise, another claimed they used the "computer to research what materials they should use to build the high-rise" (S# 14492, 5/28/15). As observed, during the investigation stage, students used the provided resources (i.e., books & computers) to research and gather information about the trout habitat (FN, 2/4/15) and the various natural disasters common to our state (FN, 3/26/15). Some group members watched videos and read articles/books while others thought about design by researching possible design solutions (FN, 1/29/15).

Increased Interaction

Many of the students' responses and field notes from class observations describing their overall experience with PBL fell within this theme. Numerous students claimed they enjoyed group interaction as it allowed them to take control of their own learning experience. It was evident through classroom observations that both activities were engaging for the students resulting in their full focus and attention to the problem (FN, 4/16/2015). Students described this increased interaction as cool, fun, exciting, and amusing. One student stated, "It was fun working with friends, I learned a lot" (S# 14464, 5/27/15). Another student claimed, "It was very fun, amusing, and lots of learning" (S# 14460, 5/28/15). While another stated, "Working together in a team at the end [leads to] success" (S# 14479, 5/27/15).

In addition to teamwork and group collaboration, student-teacher interaction was also highly visible in the PBL environment during classroom observations. The teacher acted as the facilitator by constantly walking around the classroom to scaffold the learning, asked and answered questions, interacted with groups, and provided guidance. Several students' described the teacher in the PBL environment more responsive and interactive. Student-teacher interaction is evident in the following statement: "Mrs. L was very helpful, she was always checking up on us" (S# 14458, 5/27/15). Another student claimed, "I liked having the teacher walk around. She was always there when my team needed help" (S# 14451, 5/28/15). Additionally, another student stated, "Amazing experience and the teacher was so helpful, she walked [around] all the time instead of sitting at her desk" (S# 14479, 5/27/15). Through classroom observations, we can confirm the teacher played a vital role in the learning process. This was determined by students' comments, which indicated the teacher's well preparedness in the classroom and interactions with the PBL teams. A student pointed out "It was a lot better than the teacher talking all the time; we got to decide our roles and do the work ourselves. I think I like learning like this. Can we do more stuff" (S# 14496, S# 5/28/15)?

Design and Engineering

The third very prominent theme in the data set was design and engineering. They particularly liked the design, engineering, and implementation aspect of the STEM integrated PBL environment. This excitement is summarized in the following statement "I liked working with everybody in my group [team] and engineering these two things that I thought I could never engineer" (S# 14453, 5/27/15). While another added: "Being able to build/engineer things was really interesting" (S# 1445, 5/27/15). Similarly, "I enjoyed building and liked the designing process" (S# 14483, 5/27/15). Students also expressed that the STEM content areas felt merged as one subject in the PBL setting. As illustrated by the following statement, "I liked using science, math, computers, engineering all together" (S# 14489, 5/28/15). While another pointed out that it made him feel like an engineer, "building was great, felt like an engineer" (S# 14483, 5/28/15). Likewise, a student claimed, "The clss [*sic*] was so much fun and engaging, we learned a lot…it was different, I got to be an engineer and [a] scientist" (S# 14498, 5/28/15). Field notes from classroom observation suggest that during the design phase students were actively involved and immersed in their designs. They were measuring, discussing, building, and revising their models enhancing their content knowledge and growing their interest in STEM content areas.

Results Summary

STEM integration has the potential for greatly enhancing our schooling system by promoting creativity and imagination to students unfamiliar with STEM content at this schooling level. As reported above, the results from the quantitative and qualitative data analysis show that students learning STEM in a PBL environment significantly improved their STEM content knowledge as measured by the two content knowledge assessments (CA1 & CA2). The improvement in their performance on the STEM content knowledge assessments (CA1 & CA2) was substantially greater than that of the TL group that learned through traditional learning methods. This noteworthy increase in performance can be attributed to limited education in these areas and increased hands-on /minds-on learning environment created by the problem-based learning approach. These young minds were delighted to solve real world problems while developing an understanding that professionals also solve similar problems on a daily basis.

The PBL group's critical thinking skills significantly improved over the course of the study as well measured by their scores on the TCT compared to the TL group. Therefore, it is reasonable to conclude that students that engage in STEM through PBL will likely show an improvement on their critical thinking skills. Their increased critical thinking can be exemplified by their enjoyment and focus to solve real world problems by mimicking the lifestyles of scientists and engineers. The groups in this study also displayed a positive attitude towards STEM education as measured by their scores on the S-STEM attitude survey. A difference was found over time from pre to post for both the PBL and TL groups. The significant main effect between the groups showed that there was a substantial improvement on PBL group's attitude towards STEM education. Again, this substantial increase in attitudes is in line with the increases seen in content knowledge assessments (CA1 & CA2).

Content analysis on the qualitative data revealed that students described that the most effective components of the PBL environment was their ability to employ multiple learning approaches to help them solve the problem scenarios. Their PBL experience was also highly engaging and interactive which incorporated design and engineering. Students' comments regarding their experiences show their liking towards the STEM integrated PBL environment. This is evident by the comment "I liked working with everybody in my group [team] and engineering these two things that I thought I could never engineer" (S# 14453, 5/27/15).

CHAPTER 6

DISCUSSION

Further insight on the benefits of implementing a problem-based learning STEM instruction versus traditional learning STEM instruction in a fourth grade setting will be discussed by analyzing and deliberating the results from Chapter 5. The discussion of these results from Chapter 5 will made with respect to the research questions and hypotheses of the overall research study. Finally, limitations of this study and potential future work will be presented.

Purpose of the Study Restated

There were two main objectives of this study. The first goal of this study was to investigate the effect of an integrated STEM curriculum implemented through problem-based learning instructional method in comparison to a traditional learning method in a fourth grade setting. The students' content knowledge, critical thinking skills, and their attitudes towards STEM are compared quantitatively. A second goal is to investigate the views held by students regarding the problem-based learning instructional method using a qualitative approach.

The effect of problem-based learning on students' content knowledge and critical thinking skills particularly in secondary and post-secondary education is discussed in the literature with the effects of an integrated curriculum well documented. Nevertheless, studies examining the effect of problem-based learning in combination with a STEM integrated curriculum developed using the NGSS standards (Achieve, Inc., 2013), implemented in an elementary classroom lacks research support (Duran & Şendağ, 2012;

Kettler, 2014; Murphy & Mancini-Samuelson, 2012; Wheland et al., 2013). This study aims to fill the void in literature by using an assimilated curriculum facilitated through problem-based learning in an attempt to augment students' critical thinking skills and content understanding while developing positive attitudes towards STEM content areas.

Question 1: Impact of PBL on STEM Content Knowledge

The first research question investigated the effect of the PBL instructional method on fourth grade students' STEM content knowledge as compared to traditional learning. More specifically, it examined whether differences existed between PBL and TL groups' content knowledge as measured by the scores on the two content knowledge assessments (CA1 & CA2) resulting from two different types of instruction. As hypothesized, the finding from the mixed repeated within-between measures ANOVA showed that over the course of the study, the PBL group showed statistical significance. The effect size for all these changes was large indicating a practical significance that has increased bearing on instructional practices. Likewise, research has proven PBL to be an effective method for improving content knowledge, recall, and retention (Albanese & Mitchell, 1993; Barrows, 2000; Colliver, 2000; Dochy et al., 2003; Goodnough & Nolan, 2008; Hmelo-Silver, 2004). This increase in content knowledge among the students in treatment group is attributed to two reasons, the PBL methodology and the PBL environment.

The results suggest that the PBL instructional methodology was the driving mechanism for enhanced content knowledge exhibited by the treatment group. The PBL method allows students to engage in the learning by actively connecting their prior knowledge to new knowledge gained through researching and applying a minds-on approach to promote learning of various disciplines. Students in the PBL group spent majority of the time generating ideas and developing action plans for assessing necessary information they needed to solve the problem. The continuous process stimulated the learning resulting in concrete understanding of STEM concentrated areas. The integration of STEM in the PBL group's teaching forced students to utilize skills, such as science and engineering practices similar to professionals to ask questions, brainstorm ideas, gather information, design, and test their prototype. For example, students in the PBL group, like common real-world professionals, had to find a viable solution for the problem at hand. The students were presented with the problem without any direction on how to solve it. Before embarking on solving the problem, they had to reflect on the problem, break it down using the need to know chart and recognize the information they needed to gather before initiating the design process. As they collected information they learned the science content and learned about various materials for designing, as well as applied mathematics skills to solve one problem. Furthermore, PBL methodology allowed them to distinguish between the necessary versus unwarranted information. In other words, all the information they collected through the research had to be filtered before it could be applied. This allowed them to develop problem-solving skills, which are important component for testing taking today.

Another potential reason for such changes in the PBL group was a result of the PBL environment itself. In the PBL environment learning was self-regulated with ample amount of time spent on group interaction, discussion, research, and design. In contrast, TL environment was teacher-centered and the information was directly delivered to the students through lectures. Students in the TL group were passive receivers of information as compared to the PBL group. This ability for students' in the treatment group (PBL) to be actively involved in learning as they connected new knowledge to prior knowledge stimulated the learning process, hence motivating them to learn in order to solve the problem (Greenwalk, 2000; Azar & Sungur, 2007). The PBL environment unlike the TL environment, students are not able to simply tune out during instruction as they must be keenly thinking in order to provide an explanation and reasoning for their problem solutions. For example, students in PBL were watching videos, reading articles/books, and taking notes individually. The information they received was then shared with their teammates. It was the responsibility of each team member to understand some aspect of the problem, and then teach that information to the rest of their teammates. This accountability promoted individual team members to comprehend the gathered information. Basically, each student in the PBL team needed to learn the subject material before they pass the information to their teammates. Through this circular progression, students developed a sound understanding of the content being taught.

Question 2: Impact of PBL on Critical Thinking Skills

Critical thinking skills are essential for educational and workplace success as it yields creativity and outward thinking necessary in the world today. Mulnix and Vandergrift (2014) suggest that STEM graduates not only need to be strong in content area, but should also have the aptitude to critically think. In order to build a strong understanding of STEM content areas, it is vital for students to increase their critical thinking skills. Considering this, the second research question of this study examined the effect of PBL instructional method on fourth grade students' critical thinking skills. It specifically inspected whether differences existed between the critical thinking skills of the PBL (treatment) and TL (control) group as measured by test scores on the Critical Thinking Test (TCT). As hypothesized, the finding from the mixed repeated within-between measures ANOVA showed that over the course of the study, students in the PBL group showed a statistically significant improvement in critical thinking skills as compared to the TL group students. The effect size for all these changes was large indicating that as a result of PBL instruction students in the treatment group displayed extensive improvements in their critical thinking skills. The change in the treatment groups' critical thinking skills in this study is attributed to the PBL problem and content integration. This finding is similar to other studies (VanTassel-Baska & Stambaugh, 2006; VanTassel-Baska et al., 2009) that have utilized the Test of Critical Thinking to investigate students' critical thinking skills at the elementary level.

The PBL methodology encompasses a problem scenario, which requires a viable solution. The nature of the problem assigned to the PBL group resulted in the students extending the boundaries of their pre-existing ideas while building upon new ideas to solve the problem. These problems must be real world situated and provide a frame of reference for the students (Lambros, 2002). For example, the first problem scenario required them to assist the principal by building an aquarium that mimics a trout habitat for their classroom, since the school did not have funds to supply one. While the second problem scenario asked them to build an earthquake proof luxury high-rise for Caesars Entertainment. In both problem scenarios, students were able to make direct connections with the problems and provide unique solutions, as the problems were open-ended. This stemmed multiple solutions encouraging them to use their imagination and creativity to find a possible solution. Through this hunt for a solution to both given problems, students developed their critical thinking skills, problem-solving skills, and decision-making skills (Barell, 2006; Barrows, 2000; Birgegard & Lindquist, 1998; Hmelo-Silver, 2004).

Nevertheless, the open-endedness of the PBL problem was not the sole reason for such improvements in the treatment group's critical thinking skills. The increase in the treatment group's (PBL) critical thinking skills were also impacted by the STEM integrated PBL problem. For each problem, students needed to utilize technological tools to learn the science then apply math and engineering skills to derive a possible design solution. The STEM integrated problem allowed students to use a minds-on and hands-on approach to learning. This STEM integrated problem encouraged students to go beyond reflection, understanding, and gathering of information, rather it required students to transfer then apply that knowledge and create a prototype. This was not simply a process of knowledge acquisition, yet more a combination of acquisition and application of knowledge driven by the STEM integrated problem. As Jones (2012) suggests, interdisciplinary experiences that are facilitated by the combination of problem-based, design-based, and/or inquiry learning strategies can have a significant impact on students' critical thinking skills. Similarly, this study showed that the multiplicity of the PBL problem coupled with STEM integration encouraged students to constantly reflect and apply higher-order thinking skills potentially leading them to improve their critical thinking skills.

Question 3: Impact of PBL on Attitude towards STEM

Learning in the classroom can only be successful when learners' are fully attentive with a positive attitude that helps encourage them to comprehend and enjoy the subject matter. The goal of the Next Generation Science Standards (NGSS) is designed to foster positive attitudes towards STEM careers in addition to increased exposure for students to science and engineering practices. Research has shown that as students' progress through traditional schooling their attitude towards science and math decreases (Liu et al., 2006; Masnicka, Valentia, Cox & Osman, 2010). The third research question investigated the effect of PBL and TL instructional method on fourth grade students' attitude towards STEM education. This question measured differences, if any, between PBL (treatment) and TL (control) group's attitude towards STEM education measured by the scores on the S-STEM attitude survey. The finding from the mixed repeated measure ANOVA supported the hypothesis that the PBL group would have a more positive attitude towards STEM areas as a result of PBL instruction. The findings from the survey supported the hypothesis that students in the PBL group had a statistically significant positive attitude towards STEM education as compared to the students in the TL group. This change in treatment groups' attitude towards STEM education can be attributed to the duration of the study and early exposure to STEM.

Real world problems vary in complexity with some requiring more time and information to solve than others. The complexity of a problem and or lack of exposure to these types of scenarios can make problem solving more challenging. Likewise, in PBL methodology, at times the given problem cannot be solved within the allotted time period, hence promoting students to utilize various skills and knowledge to reach a solution over an extended period of time. In this study, students in the PBL group worked on two STEM integrated problems for over 12 weeks to come to a valid solution. Throughout each of the PBL units, students were immersed in gathering data, critically thinking on how to use the collected information, discourse among classmates and/or teacher, and embarked on the building or design process. They applied both skills used in science and math (i.e., asking questions, inferring, collecting, measuring, and experimenting) along with engineering to find a possible design solution. The PBL instructional method allowed students to be actively engaged in the learning, while encouraging them to be reflective and creative unlike a traditional classroom setting. This constant delving into various knowledge base and application of multiple skills over several weeks allowed them to develop an interest in STEM content areas triggering a shift towards a more positive attitude in STEM education (Nugent et al., 2010).

The open-endedness of science requires investigation and experimentation, which encourages children to have a liking for science. According to Jarvis and Pell (2002), younger children express more positive attitudes concerning science than older students. Moreover, researchers have found that exposure to integrated activities have a positive impact on students' attitude (DeJarnette, 2012; Furner & Kumar, 2007). This spark in interest due to early exposure is another reason for an increase in the PBL group's attitude towards STEM education. Students in the PBL group were exposed to all STEM content areas through various discipline related practices. For example, students like scientists and engineers asked questions, imagined possible solution, planned out their designs and then created. Through PBL, students integrated varied content specific practices, interacted with their peers, engaged with the materials to understand the substance deeply and used their newfound knowledge to solve the given problems. The PBL STEM integrated experience captivated students by providing them with a non-traditional approach to learning of STEM as displayed in the TL group. Thus, inspiring them to engage with scientific knowledge and practices at young age making learning more meaningful and realistic. The early exposure to this new form of integrated learning through PBL prompted this shift towards a positive attitude in STEM education.

Question 4: Students' Experience in the PBL Environment

Positive classroom experiences are always memorable and yield reflection with increased productivity. The objective of this study was to determine the experiences associated with using a problem-based learning approach for STEM integration. Therefore, it is essential to gauge if the treatment group (PBL) had a positive experience during the instruction phase. To understand the PBL students' experiences, a PBL questionnaire regarding their experiences in the PBL environment was completed by the students during the post instruction phase and examined qualitatively. This questionnaire was supplemented by classroom observations and field notes taken throughout the instruction phase of the study. Content analysis conducted on the PBL questionnaire responses and field notes revealed three major themes across the data set. These themes include learning approach utilized to solve the PBL problem, increase interaction between students and teacher, and the inclusion of design and engineering in the PBL environment.

Learning Approaches

Students in the PBL environment described using multiple learning approaches to help them solve the problems. Many experts emphasize that a PBL problem should be 'ill structured', or a problem that does not provide all the necessary information (Chin & Chai, 2008; Gallagher, Stepien, Sher, and Workman, 1995; Hmelo-Silver, 2004; Lambros, 2002). Some students indicated that they used their prior understanding of science and mathematics, which they connected with newly acquired knowledge to assist them in deriving possible solutions. Other students indicated they used computers to conduct research to gather data in order to come up with possible solutions. It is often stated in education that 'one size does not fit all' (Tomlinson, 2009), this also holds true for problem type solutions. In PBL, there are multiple solutions to a given problem allowing students to find solutions in the best way they see fit. Moreover, in this study, due to STEM integration, the multi-dimensional problem encompassed various solutions along with application of diverse approaches and practices. For example, students' prior knowledge in science was activated with the specific content of the problem, such as habitat in the first problem scenario and natural disasters in the second problem. While, for both problem scenarios, math prior knowledge was applied in measurements such as, calculating the area of the table on which the aquarium would be situated. Using their pre-existing knowledge students made inferences about the new knowledge in order to connect and apply it to the problem that they were attempting to solve. The combination of prior and attained knowledge in science and math allowed the students to initiate the engineering design process. Chi (2009) argues that constructive learning, whereby students create inferences and new connections beyond what is presented is better than active learning, in which old knowledge is retrieved and activated. It was this multiplicity of the STEM integrated problem that promoted students to execute it in variety of ways during the course of this study.

Increased Interaction

Interaction is an important aspect of a child's upbringing, which allows them to maneuver through life's challenges. This interaction shapes their lives and provides meaningful learning experiences. Similarly, the increased interaction demonstrated during the instruction phase can be identified as a beneficial theme from this research study. This increased interaction was exhibited between the students and teacher. Several students indicated that throughout the PBL activities they worked with their teams to discuss ideas and collaborated with their peers. They described this element of the PBL experience as highly engaging and student-centered. Students asserted that this engaging environment inspired them to learn and they greatly enjoyed this experience.

This finding can be supported by the definition of PBL instructional methodology. Problem-based learning as mentioned before in Chapter 2 is a student-centered approach in which problem solving and collaboration leads to knowledge acquisition (Norman & Schmidt 2000; Hmelo-Silver, 2004). It is through this constant interaction, independency, dialog, and active involvement that students are able to find feasible solutions to multifaceted problems (Cook & Moyle, 2002). The PBL environment allows students to share resources, ideas, and work as a team. This partnership encourages students to develop and maintain positive group learning behaviors. In this study, the students in the PBL group were placed on different teams. They were encouraged to work and design as a team to formulate a design solution to the problem. Parallel to how professionals today are constantly interacting with their work colleagues to find solution to real-world problems, each team had to collaborate within their teams to determine how to solve and accomplish problem task. Through this interaction and teamwork students learned to compromise and accept various perspectives on a given solution.

Moreover, many students pointed out that in the PBL environment, the teacher was very helpful and augmented the learning. She scaffolded the learning by providing guidance during PBL activities. The role of the teacher in the PBL environment can justify this increased interaction between the teacher and the students. The teacher plays the role of a facilitator in a PBL environment. Jadallah (2002), states that the immense social involvement of the teacher in the PBL classroom cultivates student inquiry and knowledge construction. Similarly, in this study, the teacher was highly motivating as she monitored the student learning. For example, during the initial presentation of the question to activate the students' prior knowledge, the teacher asked questions regarding the topic being presented. The students received guidance from the teacher during the research stage, while during the design stage; she again asked questions as she monitored their progress to get them to think critically about their design. Throughout the PBL unit plans the teacher was keenly engaged with the students. This increased interaction as a result of PBL instructional method supports the finding associated with the improvement in the PBL group's critical thinking skills.

Design and Engineering

We have all played with toys when we were young and wondered, "How does this work?" Or looked at a big structure and thought, "How was this built?" These are common questions all children have; yet we seldom promote investigation upon them assuming the answer or solution may be too complex for these young minds to comprehend. These queries can all be addressed with an understanding of design and engineering, which was the most noticeable theme in the data set. Countless number of students commented on how much they enjoyed the implementation of design and engineering in the PBL environment. Many asserted that it was the best part of their PBL experience. These comments correlated with the classroom observations during the self-regulated investigation stage, while students were immersed in creating and testing their models.

Students' extreme liking for design and engineering can explain the significant difference found in the S-STEM survey between the PBL and TL group in regards to their attitude towards STEM. It can also justify that PBL can foster STEM integrated learning by providing students with rich multidisciplinary experience through problems. STEM integrated problem can provide a real work context for the students forcing them to apply cross-disciplinary knowledge to solve the PBL problem. As evident in this study, STEM integrated PBL activities have the potential to develop young children's interest in STEM. According to Robert (2013) inclusion of STEM in a science curriculum can stimulate curiosity and creativity amongst young children. Likewise, in this study, the added level of design and engineering provided students with a hands-on approach to learning science. Students mimicked field professionals as they conceptualized their design into an actual prototype. For example, they had to search for possible materials, understand the properties of those materials, and then find consumable materials that can be used to build their prototypes (i.e. using a clear plastic tub for the aquarium since they could not use glass or using a compressible material to dampen the seismic response on the structure). This implementation of engineering and design through PBL demonstrates the impact PBL has in promoting positive attitudes in STEM content areas, which can lead to a developing interest in STEM careers.

Educational Implications

Problem-based learning is a useful learning tool for STEM integration as indicated by the outcomes of this study. It has a practical relevance for improving the quality of teaching and learning in our schooling system. Educators and policy makers can use the results of this study to design STEM integrated educational programs in order to enrich students learning outcomes. This approach will yield positive results as we address the limited STEM content knowledge present in our society.

The results indicate that PBL can be especially useful in K-12 education and possibly even for students of varying developmental levels. Although, limited research studies have been conducted at the elementary level, PBL has demonstrated a positive effect on young learners (DeJarnette, 2012; Furner & Kumar, 2007; Jarvis, and Pell, 2002). In a PBL environment the learner becomes responsible for their learning. This attribute of PBL can be employed by teachers to support development of self-regulated learning, higher order thinking skills, communications skills, and escalate students' interest in learning. Problem-based instructional lessons are efficient in aiding students to acquire content knowledge. In addition to improving factual knowledge and comprehension, PBL is especially well suited for helping students apply new knowledge to varied situations or addressing problems in new settings.

Educational reform efforts have prompted policy makers to endorse constructivist teaching methodologies and a departure from the repeated use of traditional instructional methods. This change in educational practices is demonstrated by many states adopting the Next Generation science standards (Achieve, Inc., 2013) in which science and math are permeated with engineering and technology. Over the years, studies have found PBL to be an effective methodology that can be applied to various settings and content areas (Araz & Sungur, 2007; Tarhan, et al., 2008; Wong & Day, 2009; Zhang et al., 2011). Thus, it is necessary to consider pedagogies, such as PBL, that can endorse integrated

STEM learning. Problem-based learning (PBL) can foster interdisciplinary education by providing students' with rich experiences that can nurture their critical thinking skills. This exposure to multidisciplinary ideas and practices can foster a positive attitude in STEM content areas. The amalgamation of STEM content areas can kindle creativity and influence students to use their imagination when solving PBL problems. Moreover, an integrated PBL environment can offer students holistic and meaningful real-world experiences, which can prepare them for the future unlike the traditional learning environment. Therefore, educators working with students in the classroom need to think more broadly about their teaching and how it fits into real-world context. Most importantly, they need to be willing to transform their classrooms into a learning environment that fosters STEM integrated learning embedded in constructivist views of teaching.

Suggestions for Future Research

This study adds to literature regarding how an assimilated STEM curriculum facilitated through problem-based learning can amplify students' critical thinking skills, content understanding, and develop positive attitude in STEM. The current study can be expanded to include a longitudinal study of this specific PBL experience. This will provide insight on whether implementation of a STEM integrated PBL environment, as indicated in the current study, positively impacts students' learning, critical thinking skills, and attitudes toward STEM.

Alternate avenues for future research can also include the use of different student populations (i.e. high school students, engineering students, science methods students, etc.), different sampling techniques, and different content areas to determine whether the findings and implications of this study are generalizable to other populations and/or other learning contexts. The utilization of different student populations and different content areas would allow future researchers to determine whether the PBL experience is effectual with various populations in other educational environments and content areas.

Furthermore, deviating from the students' PBL experience, research is lacking on the teacher's experience within the PBL environment (Ertmer, 2010). Exploring the teacher's experience within the PBL environment would provide insight on the overall experiences of the students' and teacher, which may provide better understanding of the PBL learning method. This in turn can help to create PBL professional developments for teachers.

Limitations

Limitations are a characteristic of all forms of educational research and this dissertation study is no exception. The following limitations of this study will be discussed in this section: 1) student population, 2) school setting, 3) role of teacher, 4) time period of study, 5) teacher as PBL/TL instructor, and 6) study design randomization.

The student population is a limitation of this study as the results presented cannot be generalizable to other populations. The participants are a representation of elementary students in several suburban southwest United States school districts (i.e. predominately Caucasian). Therefore, generalization of these results outside of this population should be done with caution.

The school setting was a limitation of this study because of convenience sampling. The selection of this elementary school was based on their desire to participate, which limits the generalizability of the results.

The role of the teacher in each environment is a limitation in this study as well. The teacher was interactive and facilitated the learning in the PBL group and delivered the content via traditional teaching methods in the TL group. Although, there was one teacher in this study that taught both groups; if/how her role impacted the learning and results of the study need to be considered.

Time period of this study is another limitation that must be considered. The study took place in the second half of the school year during which students were preparing for standardized assessments. Students completed the post critical thinking assessment during the final weeks of the study, which fell towards the end of the school year around the same time when students also completed their standardized testing. Students' significant gains on the critical thinking assessment could be attributed to time the TCTpost was conducted. Therefore, the results of the TCT should be viewed with caution.

Another limitation of this study focused solely on the teacher, the school science specialist who taught all the classes that participated in this study. Although, the teacher was an experienced teacher and was provided PBL training in advance, the training was not standardized and no assessment was conducted to assess her performance in this study. Therefore, some uncertainty exists as to whether the teacher was qualified to be a PBL instructor.

Finally, the last limitation is associated with the study's design. The randomization of the participants could not be controlled. The student participants were randomly assigned to either a treatment group or control group based on the class level, not individual level within a sample population. In this case, the results revealed no significant effect; however, demonstrating there is a lower possibility for unaccounted confounding variable but a greater level of internal validity.

APPENDIX A

DEMOGRAPHIC FORM

Gender:

_______ Male

_______ Female

Age: ______

Classroom Teacher: _______________________________

Science Teacher: _________________________________

Race/Ethnicity:

_______ American Indian/Native American

_______ Asian/Pacific Islander

_______ Black/African American

_______ Hispanic/Latino

_______ White/Caucasian

Other: ______________

APPENDIX B

STEM ASSESSMENT TESTS

Test 1: Trout in the Classroom

Directions: Select the best answer for the questions.

Multiple Choice Questions

1. In a trout, which fin is the biggest fin and provides the "push" for the trout to start moving and also acts as a rudder for steering through the water?
   a. Dorsal fin
   b. Anal fin
   c. Adipose fin
   d. Caudal fin *

2. The extra water in a trout is excreted through…
   a. Operculum
   b. Nare
   c. Vent*
   d. Gills

3. The hard plate covering the gills in called…
   a. Operculum*
   b. Anal fin
   c. Eyes
   d. Lateral line

4. The organ used for swimming and stabilization is called….
   a. Caudal fin
   b. Dorsal fin*
   c. Adipose fin
   d. Anal fins

5. An organ that works the same way as our lungs do?
   a. Gills*
   b. Mouth
   c. Nare
   d. Eyes

6. The trout's organ that has triangle shaped pupils is called…
    a. Mouth
    b. Kype
    c. Eyes*
    d. Pelvic fins

7. This line is a sense organ running from operculum to the tail is called…
    a. Kype
    b. Lateral line*
    c. Dorsal fin
    d. Pelvic fins

8. Also used for swimming and stabilization but referred to as the "fatty" fin without rays
    a. Caudal fin
    b. Dorsal fin
    c. Adipose fin*
    d. Anal fins

9. An organ used as brakes and helps with up and down movement is called…
    a. Pectoral fins*
    b. Pelvic fins
    c. Adipose fin
    d. Anal fins

10. A trout needs ________ water to help it grow.
    a. warm
    b. cold*
    c. hot
    d. shallow

11. The young alveins get nourishment from ……
    a. insects
    b. small fish
    c. their yolk sacs*
    d. plants

12. The aquatic plants in and near a stream provide the trout with….
    a. carbon
    b. oxygen*
    c. nitrogen
    d. ammonia

13. A trout matures at age ________ and rarely lives past the age of ______
    a. one, ten
    b. five, eight
    c. three, five*
    d. two, five

14. The water temperature should be *at least* ______ ° F.
    a. 75 ° F
    b. 16 ° F
    c. 80 ° F
    d. 42 ° F*

15. The fry reach a size of _______ to _______ inches in about a year.
    a. 2 to 4 inches*
    b. 5 to 7 inches
    c. 6 to 9 inches
    d. 3 to 4 inches

16. An aquarium made out of which *type of glass* is strong enough to hold 50 gallons of water?
    a. Tiffany glass
    b. Float glass*
    c. Both
    d. None of the Above

17. Which material is best to water seal the sides of the aquarium?
    a. Elmer's glue
    b. Silicon*
    c. Metal brackets
    d. None of the above

18. What is the most efficient way to measure the capacity of an aquarium?
    a. perimeter
    b. area
    c. volume*
    d. diameter

True and False

19. ______. As in most vertebrates, the nervous system is made up of the brain, spinal column, and nerves. (T)*

20. ______. A trout has a symmetrical body. (F)*

21. _______. The lateral line on a trout's body forms a ray (T)*

22. _______. The perimeter of the aquarium is measures by adding two sides. (F)*

23. _______. The trout needs different types of shelter depending on the life cycle stage. Clean gravel and shallow pools/riffles provide nesting opportunities for spawning trout and nurseries for young trout. Boulders, woody debris, and stream bank vegetation provide areas for trout food sources and refuge for adult trout. (T)*

Open-ended Questions

24. Identify and describe the life cycle of a trout.

25. Explain how you would search for information on the Internet.

26. Trout spawn in at the bottom of a gravel stream. During the spawning season a single female trout can spawn anywhere from 200 to 8,000 eggs. If for the past two years the trout is spawning 3,000 eggs each year. How many eggs will the trout spawn in another 5 years?

27. How would you keep the water clean in an aquarium? Explain.

Test 2: It's a Bird, it's a Plane, it's a High-Rise

1. There are four layers of the Earth. They include the crust, mantel, the outer Core and?
   a. surface
   b. ocean
   c. continents
   d. Inner core*

2. The instrument used by a scientist to record tremors underground is called….
   a. Magnitude
   b. Seismograph*
   c. Richter scale
   d. Telephone

3. The Richter scale is a chart that is used to measure?
   a. A tsunami
   b. An earthquake*
   c. An eruption
   d. faults

4. Earthquakes are caused by shifting what?
   a. sands
   b. seas
   c. plates*
   d. soil

5. A tsunami occurs?
   a. in a desert
   b. in a farm field
   c. in the ocean*
   d. in the mountain

6. Back 300 million years ago geologist believed that the continents we know today were crowded together in one giant land mass. They have named that land mass what?
   a. Continental Drift
   b. Pangaea*
   c. North America
   d. Europe

7. Mountains created by crustal plate collision, much like what happens when you push a sheet together is called what?
   a. Dome shaped mountains
   b. Folded mountains*
   c. Fault Block Mountains

8. Mountains created on a fault where the rock is brittle and rigid, such as in the Sierra Nevada Mountains, are called?
   a. Dome shaped mountains
   b. Folded mountains
   c. Fault Block Mountains*

9. Melted rock below the Earth's surface
   a. lava
   b. magma*
   c. slush
   d. igneous rock

10. The convergent plate boundary collides twice every 24 hours. How many times will it collide in 5 days?
    a. 75 times
    b. 120 times
    c. 60 times
    d. 10 times*

11. A building made from which material will crack easily during an earthquake..
    a. Brick
    b. Wood
    c. Reinforced concrete*
    d. None of the above

12. The distance from your high-rise apartment to your closest neighborhood park is 2 miles. How many kilometers is that?
    a. 5.2 km
    b. 1.9 km
    c. 3.2 km*
    d. 6.0 km

13. Two geologic surveys of the same area, made 50 years apart, showed that the area had been uplifted 5 centimeters during the interval. If the rate of uplift remains constant, how many years will it take for this area to be uplifted a total of 70 centimeters?
    a. 350 years
    b. 250 years
    c. 700 years*
    d. 500 years

14. What material will damage the quickest in the event of a flood?
    a. Ceramic tile
    b. Drywall*
    c. Copper pipes
    d. Glass windows

15. In a high-rise building, preparation for which natural disasters in a sequence should be a priority?
    a. Earthquakes Flood, Category 5 Hurricane
    b. Earthquakes, Category 5 Hurricane, Flood
    c. Flood, Category 5 Hurricane, Earthquakes
    d. All must be a priority*

16. The high-rise will be designed in an area that is prone to a lot of earthquakes. What should be **least** important to factor to consider?
    a. The type of soil in the area
    b. How packed down the soil is
    c. How old the soil is*
    d. How thick the soil layers are in the area

17. How could you design the foundation of a high-rise building to help it stay standing in an earthquake? Choose the **best** answer.
    a. Make the foundation as deep as possible*
    b. Make the foundation as hallow as possible
    c. Make the foundation as thick as possible
    d. The building should not have a foundation

True and False

18. ______. The property of a material that enables it to resist fracture due to high impact loads is called toughness. (T)*

19. ______. Nevada is located in the southeast region of the Unites States. (F)*

20. ______. Ring of fire in an area where large number of earthquakes occurs. (F)*

21. ______. A seismometer is used to measure the effect of a hurricane. (F)*

22. ______. A geological engineer is some that designs and builds structures. (F)*

Open ended

23. Describe ways you and your family can prepare for a natural disaster?

24. Amy, Joan, and Kevin each find a rock. Amy’s rock weighs 20.82 grams. Joan’s rock weighs 20.78 grams. The weight of Kevin’s rock is between the weight of Amy’s rock and the weight of Joan’s rock. What is a possible weight, in grams, of Kevin’s rock? Explain your thinking.

25. Describe the process of designing a high-rise resistant to earthquakes.

APPENDIX C

THE CRITICAL THINKING TEST

Student Instructions:

Today you are going to take a test called The Test of Critical Thinking. How well you do on this test will not affect your grade in this class. During the next 45 minutes, you will read some short stories. After you read each story carefully, you will answer some questions. Think carefully about each possible answer and choose the best one. You will mark all of your answers on the answer sheet. **Please do not place any marks in the test packet**. Some questions ask you about what happened in the stories and some ask you what *might* happen.

The stories and questions are like the sample question that we will do together. Let's look at the example below.

SAMPLE

Nathan and Sean were in the same math class. Their teacher returned the tests she had graded. When they saw their grades, Nathan smiled, but Sean looked unhappy. The teacher said that many students had received low grades and she hoped they would study more for the next test.

Read each question and mark the BEST answer on the answer sheet.

S-1. Based on this story, what is MOST LIKELY to be true?

a. Nathan received a better grade on the test than Sean did.

b. Nathan usually receives better grades than Sean in math.

c. Sean had expected to do better on the test than he did.

d. Sean did not do as well on the test as he would have liked.

S-2. What does the teacher believe?

a. Studying helps students do well on math tests.

b. Many students did not study for the test.

c. None of the students studied enough for the test.

d. Students cannot do well in math without studying.

Explanation of answers for sample story

S-1. **Based on this story, what is MOST LIKELY to be true?**

a. **Nathan received a better grade on the test than Sean did.** This answer is INCORRECT.

Nathan seemed happier with his grade than Sean did, but we do not know who actually received a higher grade. If Nathan usually receives C's, he might have received a B and been very happy. If Sean usually receives A's, he might be unhappy with an A-minus.

b. **Nathan usually receives better grades than Sean in math**. This answer is INCORRECT.

We cannot tell from the story what grades these two students usually receive.

A. Sean had expected to do better on the test than he did. This answer is INCORRECT. We know Sean seems to be unhappy about his grade, but we do not know if he expected a better grade. Even if Sean expected to do badly on the test, he might still have been unhappy with a low grade.

B. Sean did not do as well on the test as he would have liked. This is the CORRECT answer. Sean looked unhappy when he saw his test grade, so we can conclude that he most likely did not do as well as he would have liked.

S-2. **What does the teacher believe?**

A. Studying helps students do well on math tests. This is the CORRECT answer. The teacher said that many students had not done well and she hoped they would study more for the next test. We can conclude from this statement that the teacher believes studying helps students do well on math tests.

B. **Many students did not study for the test.** This answer is INCORRECT. The teacher's statement suggests that she believes many students did not study enough, but not that they did not study at all.

C. **None of the students studied enough for the test**. This answer is INCORRECT. The teacher's statement suggests that she hopes the students who had not done well should study more. She did not say the students who had done well needed to study more.

D. **Students cannot do well in math without studying.** This answer is INCORRECT. The teacher's statement suggests that she believes studying more would help the students who did not do well to do better on the next test. But she may also believe that some students can do well in math without studying.

Read each story and the questions that go with it carefully. Mark the best answer to each question on your answer sheet. Please do not place any marks in the test packet.

STORY 1

Natalie and Robert are in the same gym class. Natalie was the fastest runner in the class. Robert did the most pull-ups. Each student claimed to be the best athlete in the class. David said neither one could be the best because both students are short and tall people are usually better athletes. After a lot of talking, the students agreed to let their friend Simon decide who the best is.

1. Simon knew Natalie won second place in the pull-up contest and Robert was fourth in running. Robert is taller than Natalie. Why did Simon **MOST LIKELY** choose Natalie as best athlete?
    a. Overall, Natalie did better than Robert.
    b. Simon likes Natalie better than Robert.
    c. Robert is too slow to be the best athlete.
    d. Overall, Simon thinks short people are better athletes.

2. What are Natalie and Robert disagreeing about?
    a. Is it better to be a tall or short athlete?
    b. Who should judge the best athlete?
    c. Can girls be better athletes than boys?
    d. What makes someone the best athlete?

3. What is LEAST likely to be true in this story?
    a. Natalie and Robert think short people are usually good athletes.
    b. Natalie and Robert think being the best athlete is important.
    c. Natalie and Robert think Simon will make a fair decision.
    d. Natalie and Robert think David is not a good judge of athletes.

STORY 2

Bill and Lee went camping with their parents at a local park one weekend. The park was very crowded. On Saturday afternoon, their father asked them to pick up some litter and then to go into the woods to cut branches for cooking hot dogs. The two brothers did as their father asked. As they stepped out of the woods, a park ranger stopped them. He looked at their sticks and asked, “Don’t you know that in the park you should take nothing but pictures and leave nothing but footprints?” The boys were puzzled by what the ranger had said. They told him that their father had asked them to cut the branches for cooking hot dogs. The ranger walked the boys back to their campsite and talked to their father alone. That evening, the ranger joined the family for dinner. Early the next morning, the family packed up and went home.

4. Why were the boys puzzled?
   a. The boys had only done what they were asked to do.
   b. The boys had taken only a few branches from the woods.
   c. The boys did not understand the ranger’s question.
   d. The boys thought it was okay to cook hot dogs.

5. What is the most likely reason the ranger talked to the father?
   a. To explain that the boys had cut too many branches
   b. To explain proper park behavior
   c. To explain why boys should not be alone in the woods
   d. To explain why people should take pictures in the wood

6. What was the MOST LIKELY reason the family went home the day after the ranger visited?
    a. The ranger had told the family to leave.
    b. The family had planned to leave that day.
    c. The ranger had upset the family.
    d. The family had no more sticks for cooking hot dogs.

7. What did the ranger think when he asked; "Don't you know that in the park you should take nothing but pictures and leave nothing but footprints"?
    a. He thought the boys should have known how to behave in the park.
    b. He thought the boys should have been taking pictures.
    c. He thought the boys were going to make a fire in the woods.
    d. He thought the boys were afraid of getting in trouble.

8. Why might the ranger tell other children this story?
    a. To teach them to pick up litter in the park.
    b. To teach them to obey their parents while camping.
    c. To teach them to protect the trees in the park.
    d. To teach them to be honest with park rangers.

9. Why did the ranger talk to the boys' father ALONE?
    a. To complain about the boys' behavior
    b. To tell the father the family had to leave the park
    c. To find out if the boys were really brothers
    d. To discuss the situation without embarrassing the father

STORY 3

Carla was nervous as she stood on the stage before her performance. As she sang, the students in the audience began to laugh. Carla heard the laughing and sang even louder. By the time she had finished her song, almost everyone was laughing. The music stopped and Carla smiled and bowed. As the curtain closed, Carla's teacher wiped away tears and gave Carla a big hug. Carla was glad her song was finished. When she got home, Carla told her parents that the audience had loved her song.

10. Based on the story, what is MOST LIKELY to be true?
    - a. Carla's teacher felt sorry for her.
    - b. Carla's parents were proud of her.
    - c. Carla is a bad singer.
    - d. Carla sang a funny song.

11. Based on the story, what BEST shows that Carla may have told her parents the truth?
    - a. She was nervous about singing.
    - b. Her song made the students laugh.
    - c. She was glad when her song was over.
    - d. Her teacher gave her a big hug after her song.

12. Based on the story, how did Carla's teacher feel?
    - a. She was proud of Carla.
    - b. She was angry that the students laughed.
    - c. She felt sorry for Carla.
    - d. She was sad that Carla's parents were not there.

13. What is the LEAST LIKELY reason why Carla sang louder?

a. She wanted the students to be able to hear the song.
b. She had reached the most important part of the song.
c. She was ignoring the students who were making fun of her.
d. She had become less nervous as she sang.

14. Which statement BEST shows that Carla was prepared for her performance?

a. She kept singing while the students laughed.
b. She was glad when she was done.
c. She hugged her teacher to thank her.
d. She smiled and bowed when she was done.

STORY 4

Paco and his mother were shopping at the mall. Paco wanted a new jeans jacket like the one many of the popular kids in his class were wearing. He asked his mother to buy one for him. She said she could not afford one right then because she needed to buy a new jacket for herself. She wanted a nice jacket to wear to a meeting about a new job. Paco told her that all his friends had jeans jackets. He was afraid that if he did not get one, no one would like him. His mother listened to Paco, but she disagreed with him. She bought the jacket for her meeting. Paco said, "You care more about your new job than about me."

15. What did Paco and his mother both believe?

a. Wearing the wrong clothes can make people dislike you.
b. It is more important for adults to look good than children.
c. What you wear affects what others think of you.
d. Women's jackets cost more than boys' jackets.

16. Based on the story, what did Paco's mother think?
    a. Her meeting was more important than Paco's friendships.
    b. She needed a new jacket more than Paco did.
    c. A cheaper jeans jacket would be better for Paco.
    d. Paco's friends should care more about him than about his clothes.

17. IF all the popular kids in Paco's class wear the same type of jeans jacket, what is **MOST LIKELY** true?
    a. The jacket they wear is the best type of jeans jacket.
    b. Popular kids like the jeans jacket.
    c. Wearing the jeans jacket makes kids popular.
    d. Paco will be unpopular unless he has the jeans jacket.

STORY 5

Tanya works at a large summer camp. She is a counselor for ten campers who share a cabin. Many of Tanya's campers were often late for dinner. Tanya told the campers she would take them to a movie if everyone came to dinner on time for a whole week. All of Tanya's campers were on time for dinner that week. Tanya took them to a movie. Tanya told Mrs. Greene, the camp owner, how well the reward had worked. Mrs. Greene disagreed. She reminded Tanya that she had made a new rule for the whole camp last week. The new rule said anyone late for dinner would not get dessert. Mrs. Greene said her new rule had caused Tanya's campers to come to dinner on time. Tanya did not argue with Mrs. Greene. But, she was sure that her reward, not the new rule, had gotten her campers to come to dinner on time.

18. What caused Tanya's campers to come to dinner on time?
    a. Mrs. Greene's rule
    b. Tanya's reward
    c. Neither the rule nor the reward
    d. There is no way to know

19. What do Tanya and Mrs. Greene each believe?
    a. Punishments work better than rewards.
    b. Her own action changed the campers' behavior.
    c. Campers who are late for dinner are rude.
    d. Campers who are on time for dinner should be rewarded.

20. What is the main question in this story?
    a. Does reward work better than punishment?
    b. Does Tanya know more about campers' behavior than Mrs. Greene?
    c. What can be done to make campers come to dinner on time?
    d. Why did Tanya's campers come to dinner on time?

21. What would Tanya MOST LIKELY tell her campers if they stopped making their beds?
    a. They should behave better.
    b. She would tell Mrs. Greene about their behavior.
    c. She would give them popcorn if they made their beds.
    d. She would send them to bed early if they did not make their beds

STORY 6

Juan took apart an old wooden clock, piece by piece. Juan's sister, Maria, was happy to sit and watch him. After taking apart the old clock, Juan looked closely at each piece. He wiped each wheel and gear with an oily cloth. He put all of the pieces on a table. Juan rubbed his hands together and looked at his watch with concern. He worked to put all of the small pieces back together. Much later, when Juan looked out the window, he saw his parents get out of their car. He looked at his watch and smiled.

22. Why did Juan look at his watch with concern?
    a. He wasn't sure his watch was working.
    b. He was afraid his parents would be angry.
    c. He hoped to finish before his parents arrived.
    d. He found the job was taking longer than he had hoped.

23. Why did Juan take the clock apart?
    a. He wanted to fix a broken part.
    b. He wanted to clean the clock.
    c. He wanted to see inside the clock.
    d. He wanted to see how clocks work.

24. Why did Juan look at his watch and smile?
    a. He had finished the clock in time.
    b. His watch was working well.
    c. His parents had arrived on time.
    d. He had a surprise for his parents.

25. What would MOST LIKELY have happened if Juan had not finished the clock before his parents arrived?
    a. Maria would have been upset.
    b. Maria would have had to explain everything.
    c. Juan's parents would have been angry.
    d. Juan would have been disappointed.

26. What BEST shows that Juan is careful?
    a. He checked to see how long his work was taking.
    b. He asked his sister to watch him work.
    c. He checked every part of the clock.
    d. He was proud when he finished the clock.

27. IF you expect Juan to be punished if his parents see him with the clock, what are you assuming?
    a. Juan was supposed to have been watching Maria.
    b. Juan was supposed to fix the clock before his parents arrived.
    c. Maria and Juan were not supposed to make a mess.
    d. Juan was not supposed to touch the clock without permission.

STORY 7

Mr. Kelso's students were making paper models of the sun and planets to put on the classroom wall. They made Earth the size of a quarter and colored it blue and green. The students wanted the sun and the other planets to be just the right size compared to Earth. Mars was red and smaller than Earth. The bright yellow sun had to be nearly nine feet tall! Several students suggested that their planets and sun should be the right distance from each other, just as they are in space. One student, André, said that the planets and the sun could not fit in the same classroom. The other students didn't believe André. He offered to explain. The students looked at Mr. Kelso, who smiled and nodded. The students decided to make the sun and planets smaller.

28. Why did André say the sun and planets would not fit in the same classroom?

   a. He wanted to make Mr. Kelso smile.
   b. He wanted to start an argument.
   c. He wanted to help the other students.
   d. He wanted the sun to be smaller.

29. What extra information did André use to make his conclusion?

   a. The sizes of all nine planets.
   b. The distance between the planets and the sun in space.
   c. The distance between Mars and Earth in space.
   d. The size of the sun.

30. What is the most likely reason Mr. Kelso smiled and nodded?

   a. He thought it was funny that he had tricked the class.
   b. He was happy a student understood the problem.
   c. He thought that André was being funny.
   d. He was happy that the class made the planets smaller.

31. Why did the students' suggestion create a problem?

   a. The nine-foot sun was too large to fit on the classroom wall.
   b. Mr. Kelso's directions were not clear when the project started.
   c. Earth and Mars were too small to be seen clearly on the classroom wall.
   d. The size of the model planets affected how far apart they should be placed.

32. Why did the students decide to make the sun and planets smaller?

   a. The students wanted to get a good grade.
   b. The students did not believe André.
   c. The students could not do the project as planned.
   d. The students thought Mr. Kelso smiled because they were right.

STORY 8

John's friend Paul usually talks and laughs a lot during lunch. On Tuesday, Paul was very quiet during lunch. On the way to class, John asked Paul if he was upset with him and Paul said, "No." Then John asked Paul what was wrong and Paul said, "Nothing is wrong." John thought Paul might be angry because John had not chosen him for his basketball team in gym class on Friday. John decided that if Paul was not going to talk to him, he would not talk to Paul either.

33. Based on the story, what is MOST LIKELY John's point of view?
    a. He thinks Paul should not be upset about gym class.
    b. He feels sad that Paul is not talking as much as usual.
    c. He thinks something he did caused Paul to be quiet.
    d. He feels bad about not choosing Paul for his team.

34. What is the main question in this story?
    a. Why is Paul angry with John?
    b. Why was Paul quiet during lunch?
    c. Why didn't John choose Paul for his team?
    d. When will Paul talk to John again?

35. What new information would BEST show that John was wrong about why Paul was quiet?
    a. Paul was quiet during lunch on Monday.
    b. Paul and John have been best friends for a long time.
    c. Paul got a bad grade on a math test before lunch.
    d. Paul does not like to play basketball.

STORY 9

Karen and Mollie had planned to go to a movie Saturday evening. Mollie called Karen Saturday morning. She told Karen her parents would not allow her to go to the movie after all. When Karen called her friend later that evening, she was told Mollie had gone to a party. Karen was angry because her friend had gone to a party instead of a movie with her. She decided that she could not be friends with someone who did not tell the truth.

36. After talking with Mollie Saturday morning, what did Karen think Mollie would be doing that evening?
    a. Mollie would be going out with her parents.
    b. Mollie would be going to a party.
    c. Mollie would be watching TV with a friend.
    d. Mollie would be staying home.

37. What is most likely to happen next in the story?
    a. Karen will decide to end her friendship with Mollie.
    b. Mollie will call Karen to invite her to a movie.
    c. Mollie will decide to end her friendship with Karen.
    d. Karen will call Mollie to invite her to a movie.

38. What would show that Karen's thoughts about Mollie were unfair?
    a. Mollie had not known that her parents wanted her to go to a party.
    b. Mollie had changed her mind about going out with Karen.
    c. Mollie had tried to call Karen Friday night to change their plans.
    d. Mollie had never lied to Karen in the past.

39. What BEST shows that the story is told from Karen's point of view?

   a. Karen and Mollie planned to go to a movie together.
   b. Mollie called Saturday morning to tell Karen she could not go to the movie.
   c. Karen called Mollie and learned that Mollie was not home.
   d. Mollie went to a party instead of going to a movie with Karen.

40. What was the MOST LIKELY reason Karen called Mollie?

   a. To ask Mollie to go to a movie.
   b. To tell Mollie why she was angry.
   c. To talk to Mollie about her day.
   d. To ask Mollie if she enjoyed the party.

41. Why is it likely that Karen was NOT angry with Mollie Saturday morning?

   a. Sometimes parents change children's plans.
   b. Sometimes parties are more fun than movies.
   c. Sometimes friends don't tell the truth.
   d. Sometimes friends change their minds.

STORY 10

Lisa planted lettuce in her back yard. One morning, the leaves of the plants were smaller than they had been the day before. The edges of the leaves were ragged. Lisa concluded that her neighbor's pet rabbit had been eating her lettuce. Her neighbor said that his rabbit had gotten out of its cage the night before. But, he said, the rabbit could not have eaten Lisa's lettuce because the rabbit was trained to eat only rabbit food.

42. Based on the story, what MUST be true?

   a. Some animal ate Lisa's lettuce.
   b. Lisa's lettuce was damaged before the rabbit got out.
   c. Something happened to Lisa's lettuce the night the rabbit got out.
   d. The lettuce leaves will grow back if the rabbit stays in its cage.

43. What new information would BEST show that the rabbit ate the lettuce?

   a. A neighbor with a fence around her garden has perfect lettuce.
   b. Lisa's cousin has a rabbit that loves lettuce and rabbit food.
   c. Lisa's neighbor has been wrong about his rabbit in the past.
   d. Lisa finds ragged edges on her lettuce after the rabbit gets loose again.

44. Based on the story, what does the neighbor believe about his rabbit?

   a. His rabbit is smarter than other rabbits.
   b. His rabbit does not like to eat lettuce.
   c. His rabbit does what it has been trained to do.
   d. His rabbit will not get out of its cage again.

45. What new information, IF TRUE, would make it IMPOSSIBLE for the rabbit to have eaten Lisa's lettuce?

   a. Rabbits do not eat vegetables.
   b. Rabbits can be trained to eat only rabbit food.
   c. Rabbits do not go very far when they get loose.
   d. Rabbits cannot eat lettuce when it is covered up.

STOP

APPENDIX D

UPPER ELEMENTARY SCHOOL STUDENT ATTITUDES

TOWARD STEM (S-STEM)

Directions: There are lists of statements on the following pages. Please mark your answer sheets by marking how you feel about each statement. For example:

Example 1	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I like engineering.	○	○	○	○	○

As you read the sentence, you will know whether you agree or disagree. Fill in the circle that describes how much you agree or disagree.

Even though some statements are very similar, please answer each statement. This is not timed; work fast, but carefully.

There is no "right" or "wrong" answer! The only correct responses are those that are true for you. Whenever possible, let the things that have happened to you help you make a choice. Please fill in on only one answer per question.

Upper Elementary School Student Attitudes toward STEM (S-STEM)

Math and Science

		Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1.	Math has been my worst subject.	○	○	○	○	○
2.	I would consider choosing a career that uses math.	○	○	○	○	○
3.	Math is hard for me.	○	○	○	○	○
4.	I am the type of student to do well in math.	○	○	○	○	○
5.	I can handle most subjects well, but I cannot do a good job with math.	○	○	○	○	○
6.	I am sure I could do advanced work in math.	○	○	○	○	○
7.	I can get good grades in math.	○	○	○	○	○
8.	I am good at math.	○	○	○	○	○
9.	I am sure of myself when I do science.	○	○	○	○	○
10.	I would consider a career in science.	○	○	○	○	○
11.	I expect to use science when I get out of school.	○	○	○	○	○
12.	Knowing science will help me earn a living.	○	○	○	○	○
13.	I will need science for my future work.	○	○	○	○	○
14.	I know I can do well in science.	○	○	○	○	○
15.	Science will be important to me in my life's work.	○	○	○	○	○
16.	I can handle most subjects well, but I cannot do a good job with science.	○	○	○	○	○
17.	I am sure I could do advanced work in science.	○	○	○	○	○

Engineering and Technology

Please read this paragraph before you answer the questions.

Engineers use math, science, and creativity to research and solve problems that improve everyone's life and to invent new products. There are many different types of engineering, such as chemical, electrical, computer, mechanical, civil, environmental, and biomedical. Engineers design and improve things like bridges, cars, fabrics, foods, and virtual reality amusement parks. **Technologists** implement the designs that engineers develop; they build, test, and maintain products and processes.

		Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
18.	I like to imagine creating new products.	○	○	○	○	○
19.	If I learn engineering, then I can improve things that people use every day.	○	○	○	○	○
20.	I am good at building and fixing things.	○	○	○	○	○
21.	I am interested in what makes machines work.	○	○	○	○	○
22.	Designing products or structures will be important for my future work.	○	○	○	○	○
23.	I am curious about how electronics work.	○	○	○	○	○
24.	I would like to use creativity and innovation in my future work.	○	○	○	○	○
25.	Knowing how to use math and science together will allow me to invent useful things.	○	○	○	○	○
26.	I believe I can be successful in a career in engineering.	○	○	○	○	○

21st Century Skills

		Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
27.	I am confident I can lead others to accomplish a goal.	○	○	○	○	○
28.	I am confident I can encourage others to do their best.	○	○	○	○	○
29.	I am confident I can produce high quality work.	○	○	○	○	○
30.	I am confident I can respect the differences of my peers.	○	○	○	○	○
31.	I am confident I can help my peers.	○	○	○	○	○
32.	I am confident I can include others' perspectives when making decisions.	○	○	○	○	○
33.	I am confident I can make changes when things do not go as planned.	○	○	○	○	○
34.	I am confident I can set my own learning goals.	○	○	○	○	○
35.	I am confident I can manage my time wisely when working on my own.	○	○	○	○	○
36.	When I have many assignments, I can choose which ones need to be done first.	○	○	○	○	○
37.	I am confident I can work well with students from different backgrounds.	○	○	○	○	○

APPENDIX E

PBL QUESTIONNAIRE

Directions: Please answer the following but try to write as neat as possible.

1. Think and write down five key words that helped you solve Dr. Buck's problem about trout.

2. Think and write down five key words that helped you design a Caesars high-rise apartment.

3. Answer the following questions.
    a. How did you use science to help solve dr. Buck's problem about trout? Explain

    b. How did you use math to help solve dr. Buck's problem about trout? Explain

    c. How did you use science to create Caesars high-rise building? Explain.

    d. How did you use math to create Caesars high-rise building? Explain

4. What did you like about the scientific process?

5. What did you dislike about the scientific process?

6. Brainstorm words and write down five important words to describe your overall experience.

APPENDIX F

PROBLEM-BASED LEARNING UNIT PLANS

Unit Plan 1

Lesson Plan Title: Trout in the Classroom
Grade: 4^{th}
Acknowledgements(s): Dr. Carrie Buck, Amandalynn Lemon, Pinecrest Academy, and Nevada Wildlife
Subject: STEM (Science, Technology, Engineering, and Mathematics
Topic: *Structure. Function and Information Processing*

Standards/Objectives

Science and Engineering Practices

National, State, or District Standard

4-PS4-2 – Developing a model to describe phenomenon.
LS1. A. Plants and animals have both internal and external structures that serve various functions, in growth, survival, behavior and reproduction.
4.G.A.1. Draw points, lines, line segments, rays, angles (right, acute, obtuse), and perpendicular, and parallel lines. Identify these in two-dimensional figures.
4.G.A.3. Recognize a line of symmetry for a two-dimensional figure as a line across the figure such that the figure can be folded across the line into matching parts. Identify line symmetric figures, and draw lines of symmetry
Systems, and Systems Modeling: A system can be described in terms of its components, and their interactions. **(4-LS1-1, 4-LS2-2).**

Mathematics

MP1 - Make sense of problems and persevere in solving them.
MP3 - Construct viable arguments and critique the reasoning of others.
4MD.3 - Apply the area and perimeter formulas for rectangles in real world and mathematical problems.
4.MD.6-2: Measure angles in whole-number degrees using a protractor. Sketch angles of specified measure.

Computer Technology Standards

3.B.5.1. Use keywords Use keywords to search, organize, locate, and synthesize information in multiple sources to create an original product.
3.D.5.1. Collect, organize, analyze, and manipulate data using digital tools, and report results in a format appropriate to the task.
5.B.5.1. Use technology resources for problem solving, self-directed learning,

collaboration, and extended learning activities.

Background Information for Teacher: Caring for trout in an aquarium can be a difficult task due to their sensitivity to changes in water chemistry, temperature, and availability of dissolved oxygen. In their natural habitats in the streams trout have access to cold and clean streams, rich in dissolved oxygen, and covered by forest vegetation. Their food consists of the aquatic macro invertebrates, which also thrive in these watershed streams. Although an aquarium cannot contain all of the elements that create the natural habitats for trout, we can use equipment and tools to help trout survive until they are strong enough to be released into watershed streams.

Materials:

Various building materials
Scissors
Silicon
Making tape
Markers

Advanced Preparation of Materials:

Teacher will have materials ready for each group in a bucket.

Safety Considerations:

Be careful with the materials. Don’t throw or misuse any of the objects.

Procedures:

Teacher will pose the following problem scenario to the students:

The school principal (Dr. Buck) has been asked by the Nevada Department of Wildlife to participate in a science and engineering project. You have been selected as the lucky class who will take the lead and address a problem. In about a month the Nevada Wildlife will be dropping off about 100 tiny eggs that you will have to raise for them until they develop into a fry. But before they get delivered, you must prepare for them. However, the problem is the school doesn’t have enough money to buy an aquarium and no idea about the type of trout eggs that will be delivered. So, Dr. Buck has asked that an aquarium be designed that can easily fit into the classroom on the back table. Also the aquarium must be habitable for the eggs resembling a trout’s natural environment so they can survive.

- Students will be placed in five groups of five.
- They will read the problem scenario and reflect on the problem while writing down their ideas.
- Students will work within their groups to organize their ideas across three-focus question on the *Need to Know* worksheet.

- They will engage in investigation and design. The teacher will make observation, and facilitate the learning.
- Student will organize their data and prepare a presentation.
- Final week of the unit each group will share their presentation with the class.

Evaluation

- Teacher will conduct formative assessment through the learning through questioning and classroom observations.
- Students will complete the content knowledge assessment (CA1).

Unit Plan 2

Lesson Plan Title: It's a Bird, it's a Plane, it's a High-rise!
Grade Level: 4^{th}
Acknowledgement(s): Dr. Carrie Buck, Amanda Lynn Lemon, and the fourth grade students of Pinecrest Academy.
Subject: STEM (Science, Technology, Engineering, Mathematics)
Topic: Earth's Systems: Processes that Shape the Earth

Standards/Objectives

National, State or District Standard

Science and Engineering Practices

4-ESS2-1 - Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon.
ESS1.C - Local, regional, and global of rock formations reveal changes over time due to earth forces, such as earthquakes. The presence and location of certain fossil types indicate the order in which rock layers were formed.
ESS2.B - The locations of the mountain ranges, deep ocean trenches, ocean floor structures, earthquakes, and volcanoes occur in patterns. Most earthquakes and volcanoes occur in bands that are often along the boundaries between continents and oceans. Major mountain chains form inside continents or near their edges. Maps can help locate the different land and water features areas of Earth.
ESS3.B - A variety of hazards result from natural processes (e.g., earthquakes, tsunamis, volcanic eruptions). Humans cannot eliminate the hazards but can take steps to reduce their impacts.
Patterns: Patterns can be used as evidence to support an explanation. **(4-ESS1-1, 4-ESS2-2).**
Cause and Effect: Cause and effect relationships are routinely identified, tested, and used to explain change. **(4-ESS1-1, 4-ESS2-2).**

Mathematics

MP.2 - Reason abstractly and quantitatively.
MP.4 - Model with mathematics.
MP.5 - Use appropriate tools strategically.
4.MD.A.1 - Know relative sizes of measurement units within one system of units including km, m, cm; kg, g; lb, oz.; l, ml; hr, min, sec. Within a single system of measurement, express measurements in a larger unit in terms of a smaller unit.
4.MD.A.2 - Use the four operations to solve word problems involving distances, intervals of time, liquid volumes, masses of objects and money, including problems involving simple fractions or decimals, and problems that require expressing measurements given in a larger unit in terms of smaller unit. Represent measurement quantities using diagrams such as number line diagrams that feature a measurement scale.

Computer and Technology Standards

3.B.5.1 - Use keywords to search, organize, locate, and synthesize information in multiple sources in order to create an original product.
3.D.5.1 - Collect, organize, analyze, and manipulate data using digital tools, and report results in a format appropriate to the task.
5.B.5.1 - Use technology resources for problem solving, self-directed learning, collaboration, and extended learning activities.

Background Information for Teacher: The geology of Nevada is foundation of its Natural resource. Mountain ranges in Nevada are commonly about 10 miles wide and rarely longer than 80 miles and are separated by valleys. The geologic structure that controls this basin and-range topography is dominated by faults. Nearly every mountain range is bounded on at least one side by a fault that has been active, with large earthquakes, during the last 1.6 million years. For the last several million years, these faults have raised and occasionally tilted the mountains and lowered the basins (Price, 20014). A natural disaster is when events such as earthquakes, mudslides, floods or wildfires affect people. Despite our inability to control these events, we can plan, and prepare for them to minimize damage when they do happen. Some commons disasters in California are earthquakes, floods, wildfires, landslides, and mudslides, tsunami, power outages, extreme heat.

Materials:

Various materials for creating a structure.
Topographic map of the region and Nevada
meter sticks
Legos, seismograph

Advanced Preparation of Materials:

Teacher will have materials ready for each group in a bucket.

Safety Considerations

Be careful with the materials. Don’t throw or misuse any of the objects.

Procedures:

Teacher will pose the following problem scenario to the students:

Over the years, natural disasters have increased around the world. After Hurricane Sandy, one of deadliest hurricane that took place in New York City in October of 2012, states around the nation are concerned and have begun preparation for future natural disasters. As Nevadans we must prepare too, especially since we border a state, which is prone to several natural disasters. In light of this, Caesar Entertainment Company has hired you as their civil engineer and asked you design their new high-rise luxury apartment complex that can withstand a common natural disaster in this region.

- Students will be placed in groups of five. They will read the problem scenario and reflect on the problem while writing down their ideas.
- Students will work within their groups to organize their ideas across three-focus question on the *Need to Know* worksheet.
- They will engage in investigation and design. The teacher will make observations and facilitate the learning.
- Student will organize their data and prepare a presentation.
- Final week of the unit each group will share their presentation with the class.

Evaluation

- Teacher will conduct formative assessment through the learning through questioning and classroom observations.
- Students will take a summative assessment on the STEM content addressed in lesson (CA2).

APPENDIX G

NEED TO KNOW WORKSHEET

What's going on?

____

____

What Do We Know?	**What Do We Need to Know?**	**How Do We Find Out What we need to Know?**

APPENDIX H

CONTENT KNOWLEDGE ASSESSMENT RUBRICS

Trout in the Classroom Rubric

1. Identify the life cycle of a trout.

- Egg – alveins – fry –Trout – Spawning Trout

- *3 points = If all are identified and even if the adult and spawning adult are separately identified.*
- *2 points = If two to three stages are identified.*
- *1 point = If one to two stages are identified.*

2. Explain how you would search for information on the Internet.
I would go to the Internet and then click on Google (search engine) and type in Keywords for what I am searching.

- *1 point = mentioned an Internet browser.*
- *1 point = mentioned search engine.*
- *1 point = mentioned type in keywords (any word example).*

3. 15,000 eggs (1 point)

4. How would you keep the water clean in an aquarium? Explain.
Use a water filter to clean the aquarium. The filter removes excess food, organic matter, free-floating particles, chemicals, and fish's waste from the water.

- *1 point = If only filter written or an unreasonable explanation.*
- *2 points = If filter mentioned along with a reasonable explanation.*

Total Points on Constructed Responses = 9

It's a Bird, It's a Plan, It's a High-rise - Rubric

1. Describe ways you and your family can prepare for a natural disaster.

    - Store food, water, and essentials.
    - Outline emergency plan
    - Identify working exits.
    - Pack a go bag

    - *3 points = all of the above and additional reasonable answers are mentioned.*
    - *2 points = two to three are mentioned/ or two mentioned with other reasonable answers.*
    - *1 point = if one is mentioned or another reasonable answer.*

2. Kevin's rock is 20.80 grams because it is between 20.82 and 20.78 grams (1point).

3. Describe the process of building an earthquake resistant high-rise.

    Check the soil of the area, the land to check for seismic activity. Make a structural blueprint; create a prototype to test for stability and other structural properties. The roof should be light and make the foundation strong.

    - *4 points = if sufficient information with a proper information is stated.*
    - *3 points = valid somewhat reason but not reasonable explanation.*
    - *2 points = valid reason and no explanation*
    - *1 point = just valid reason*

Total possible point on constructed responses = 8

APPENDIX I

IRB APPROVAL NOTICE

UNLV

Social/Behavioral IRB – Expedited Review Approval Notice

NOTICE TO ALL RESEARCHERS:
Please be aware that a protocol violation (e.g., failure to submit a modification for any change) of an IRB approved protocol may result in mandatory remedial education, additional audits, re-consenting subjects, researcher probation, suspension of any research protocol at issue, suspension of additional existing research protocols, invalidation of all research conducted under the research protocol at issue, and further appropriate consequences as determined by the IRB and the Institutional Officer.

DATE: December 16, 2014

TO: **Dr. Hasan Deniz**, Teaching and Learning

FROM: Office of Research Integrity - Human Subjects

RE: Notification of IRB Action
Protocol Title: **Engineering the Path to Higher-order Thinking in Elementary Education: A Problem-based Approach for STEM Integration**
Protocol #: 1409-4940
Expiration Date: December 15, 2015

This memorandum is notification that the project referenced above has been reviewed and approved by the UNLV Social/Behavioral Institutional Review Board (IRB) as indicated in Federal regulatory statutes 45 CFR 46 and UNLV Human Research Policies and Procedures.

The protocol is approved for a period of one year and expires December 15, 2015. If the above-referenced project has not been completed by this date you must request renewal by submitting a Continuing Review Request form 30 days before the expiration date.

PLEASE NOTE:
Upon approval, the research team is responsible for conducting the research as stated in the protocol most recently reviewed and approved by the IRB, which shall include using the most recently submitted Informed Consent/Assent forms and recruitment materials. The official versions of these forms are indicated by footer which contains approval and expiration dates.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through ORI - Human Subjects. No changes may be made to the existing protocol until modifications have been approved by the IRB. Modified versions of protocol materials must be used upon review and approval. Unanticipated problems, deviations to protocols, and adverse events must be reported to the ORI – HS within 10 days of occurrence.

If you have questions or require any assistance, please contact the Office of Research Integrity - Human Subjects at IRB@unlv.edu or call (702) 895-2794.

Office of Research Integrity - Human Subjects
4505 Maryland Parkway • Box 451047 • Las Vegas, Nevada 89154-1047
(702) 895-2794 • FAX: (702) 895-0805 • IRB@unlv.edu

REFERENCES

Achieve, Inc. (2013). Next generation science standards. Retrieved from http://www.nextgenscience.org/next-generation-science-standards/

Albanese, M. A., & Mitchell, S. (1993). Problem-based learning: A review of literature on its outcomes and implementation issues. *Academic medicine*, *68*(1), 52-81.

Almehrizi, R. S. (2013). Coefficient alpha and reliability of scale scores. *Applied Psychological Measurements*, *37*(6), 438-459.

Alouf, J. L., & Bentley, M. L. (2003). *Assessing the impact of inquiry-based science teaching in professional development activities, PK-12.* Paper presented at the annual meeting of the Association of Teacher Educators, Jacksonville, FL.

Amador, J. A., & Görres, J.H. (2004). A problem-based learning approach to teaching introductory soil science. *Journal of Natural Resources and Life Sciences Education*, *33*, 21-27.

American Society for Engineering Education. (2006). The research agenda for the new discipline of engineering education. *Journal of Engineering Education,* 259-261.

Anderson, J. (2007). Enriching the teaching of biology with mathematical concepts. *The American Biology Teacher*, *69*(4), 205-209.

Apedoe, X. S., Reynolds, B., Ellefson, M. R., & Schunn, C. D. (2008). Bringing engineering design into high school science classrooms: The heating/cooling unit. *Journal of Science Education and Technology*, *17*(5), 454-465.

Asghar, A., Ellington, R., Rice, E., Johnson, F., & Prime, G. M. (2012). Supporting STEM education in secondary science contexts. *Interdisciplinary Journal of Problem-based Learning*, *6*(2), 85-125.

Araz, G., & Sungur, S. (2007). The interplay between cognitive and motivational variables in a problem-based learning environment. *Learning and Individual Differences*, *17*(4), 291-297.

Azer, S. A. (2009). Interactions between students and tutor in problem-based learning: The significance of deep learning. *The Kaohsiung journal of medical sciences*, *25*(5), 240-249.

Bächtold, M. (2013). What do students "construct" according to constructivism in science education? *Research in Science Education*, *43*(6), 2477-2496.

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching what makes it special? *Journal of teacher education*, *59*(5), 389-407.

Barell, J. F. (2007). *Problem-based learning: An inquiry approach*. Thousand Oaks: CA, Corwin Press.

Barker, B. S., & Ansorge, J. (2007). Robotics as means to increase achievement scores in an informal learning environment. *Journal of Research on Technology in Education*, *39*(3), 229-243.

Barrows, H. S. (2000). *Problem-based learning applied to medical education*. Carbondale: IL, Southern Illinois University School of Medicine.

Basham, J. D., & Marino, M. T. (2013). Understanding STEM education and supporting students through universal design for learning. *Teaching Exceptional Children*, *45*(4), 8-15.

Batdı, V. (2014). The effects of a problem-based learning approach on students' attitude levels: A meta-analysis. *Educational Research and Reviews*, *9*(9), 272-276.

Beaudoin, C. R., Johnston, P. C., Jones, L. B., & Waggett, R. J. (2013). University support of secondary STEM teachers through professional development. *Education*, *133*(3), 330-339.

Becker, K., & Park, Kyungsuk. (2011). Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis. Journal of Stem Education, 12(5-6), 23-37.

Berghel, H. (2014). STEM revisited. *Computers*, 7-73

Berkson, L. (1993). Problem-based learning: have the expectations been met? *Academic Medicine*, *68*(10), S79-88.

Berlin, D. F., & White, A. L. (1998). Integrated science and mathematics education: Evolution and implications of a theoretical model. *International handbook of science education*, *1*, 499-512.

Berlin, D. F. & White, A. L. (2012). A longitudinal look at attitudes and perceptions related to the integration of mathematics, science, and technology education. *School Science and Mathematics*, *112*(1), 20-30.

Bevevino, M. M., Dengel, J., & Adams, K. (1999). Constructivist theory in the classroom internalizing: concepts through inquiry learning. *The Clearing House*, *72*(5), 275-278.

Biggs, J. (1999). What the student does: teaching for enhanced learning. *Higher Education Research & Development*, *18*(1), 57-75.

Biggs, J. (2003). Aligning teaching and assessing to course objectives. *Teaching and Learning in Higher Education: New Trends and Innovations*, *2*, 13-17.

Biggs, J., & Tang, C. (2007). *Teaching for quality learning at university*. Berkshire, UK: Open University Press.

Bilgin, I., Senocak, E., & Sözbilir, M. (2009). The effects of problem-based learning instruction on university students' performance of conceptual and quantitative problems in gas concepts. *Eurasia Journal of Mathematics, Science & Technology Education*, *5*(2), 153-164.

Birgegard, G., & Lindquist, U. (1998). Change in student attitudes to medical school after the introduction of problem-based learning in spite of low ratings. *Medical Education, 32*, 46-49.

Bracken, B. A., Bai, W., Fithian, E., Lamprecht, M. S., Little, C., & Quek, C. (2003). *The test of critical thinking*. Williamsburg, VA: Center for Gifted Education, College of William & Mary.

Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, M. C., (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, *112*(1), 3-11.

Brown, S. W., Lawless, K. A., & Boyer, M. A. (2013). Promoting positive academic dispositions using a web-based PBL environment: The GlobalEd 2 Project. *Interdisciplinary Journal of Problem-based Learning*, *7*(1), 67-90.

Burris, S., & Garton, B. L. (2007). Effect of instructional strategy on critical thinking and content knowledge: Using problem-based learning in the secondary classroom. *Journal of Agricultural education*, *48*(1), 106-116.

Cantrell, P., Pekcan, G., Itani, A., & Velasquez-Bryant, N. (2006). The effects of engineering modules on student learning in middle school science classrooms. *Journal of Engineering Education*, *95*(4), 301-309.

Chalmers, A. F. (1999). *What is this thing called science?* (3rd ed.). Indianapolis: Hackett Publishing.

Chen, C. F., Tomsovic, K., & Aydeniz. M (2014). Filling the Pipeline: Power System and Energy Curricula for Middle and High School Students Through Summer Programs. IEEE TRANSACTIONS ON POWER SYSTEMS, 29(4), 1874-1879

Chi, M. T. H. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science, 1*, 73-105.

Chin, C., & Chia, L. G. (2008). Problem-based learning tools. *Science Teacher*, *75*(8), 44-49.

Choo, S. S., Rotgans, J. I., Yew, E. H., & Schmidt, H. G. (2011). Effect of worksheet scaffolds on student learning in problem-based learning. *Advances in health sciences education*, *16*(4), 517-528.

Cichon, D., & Ellis, J. G. (2003). *The effects of MATH Connections on student achievement, confidence, and perception*. In S.L. Senk & D.R. Thompson (Eds.), Standards-based school mathematics curricula: What are they? What do students learn? (pp. 345-374). Mahwah, N.J.: Lawrence Erlbaum Associates.

Clark, A. C., & Ernst, J. V. (2007). A model for the integration of science, technology, engineering, and mathematics. *The Technology Teacher*, *66*(4), 24-26.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). New Jersey: Lawrence Erlbaum.

Colliver, J. A. (2000). Effectiveness of problem-based learning curricula: Research and theory. *Academic Medicine*, *75*(3), 259-266.

Conaway. C. (2007). Supply and demand of STEM workers: STEM jobs are growing, but are enough Massachusetts students qualified? *Massachusetts Department of Education.* Retrieved July 19, 2014, from http://www.doe.mass.edu/research/reports/priority.aspx?section=Other&yr=2007.

Cook, M., & Moyle, K. (2002). Students' evaluation of problem-based learning. *Nurse Education Today*, *22*, 330-339.

Cooney, T., DiSpezio, M. A., Foots, B. K., Matamoros, A. L., Nyquist, K. B., & Ostlund, K. L. (2002). *Scott Foresman Science.* Glenview, Illinois: Scott Foresman and Company

Cortina, J. M. (1993). What is coefficient alpha? An examination of theory and application. *Journal of Applied Psychology*, *78* (1), 98-104.

Cotabish, A., Dailey, D., Robinson, A., & Hughes, G. (2013). The Effects of a STEM Intervention on Elementary Students' Science Knowledge and Skills. *School Science and Mathematics*, *113*(5), 215-226.

Cotič, M., & Zuljan, M. V. (2009). Problem-based instruction in mathematics and its impact on the cognitive results of the students and on affective motivational aspects. *Educational studies*, *35*(3), 297-310.

Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching, 37*(9), 916-937.

Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five approaches* (2nd ed.). London: Sage.

Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed method approaches* (3rd ed.). Thousand Oaks, CA: Sage Publications, Inc.

Cunningham, D. J., Schreiber, J. B., & Moss, C. M. (2005). Belief, doubt, and reason. *Educational Philosophy and Theory*, *37*(2), 177-189.

Czernik, C. M., Weber, W. B., Sandmann, A., & Ahern, J. (1999). A literature review of science and mathematics integration. School Science and Mathematics, *99*, 421- 430.

Daugherty, M. K. (2010). *The 'T' and 'E' in STEM. In ITEEA (Ed.), The Overlooked STEM Imperatives: Technology and Engineering*. Reston, VA: ITEEA.

Davis, B., Sumara, D. J., & Luce-Kapler, R. (2000). *Engaging minds: Changing teaching in complex times*. Mahwah, NJ: Lawrence Erlbaum Association, Inc.

Dearing, B. M. & Daugherty, M. K. (2004). Delivering engineering content in technology education. *The Technology Teacher*, *64*(3), 8-11.

De Camargo Ribeiro, L. R. (2008). Electrical engineering students evaluate problem-based learning (PBL). *International Journal of Electrical Engineering Education*, *45*(2), 152-161.

Delisle, R. (1997). *How to use problem-based learning in the classroom.* Alexandria, VA: Association for Supervision and Curriculum Development.

DeJarnette, N. K. (2012). America's children: Providing early exposure to stem (science, technology, engineering, and math) initiatives. *Education*, *133*(1*),* 77-84.

Dewey, J. (1938). *Experience and education*. New York: Mac Millian.

Dewey, J. (1933). *How we think*. Boston: D. C. Heath.

Diamond, B. S., Maerten, Rivera, J., Rohrer, R. E., & Lee, O. (2014). Effectiveness of a curricular and professional development intervention at improving elementary teachers' science content knowledge and student achievement outcomes: Year 1 results. *Journal of Research in Science Teaching*, *51*(5), 635-658.

Dixon-Krauss, L. (1996). *Vygotsky in the Classroom: Mediated Literacy Instruction and Assessment*. Reading, MA: Addison Wesley Longman, Reading.

Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and instruction*, *13*(5), 533-568.

Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, *23*(7), 5-12.

Duran, M., & Sendag, S. (2012). A Preliminary Investigation into Critical Thinking Skills of Urban High School Students: Role of an IT/STEM Program. *Creative Education*, *3*(02), 241-250.

Eisenhart, M., Finkel, E., & Marion, S. F. (1996). Creating the conditions for scientific literacy: A re-examination. *American Educational Research Journal*, *33*(2), 261-295.

English, L. D., Hudson, P., & Dawes, L. (2013). Engineering-Based Problem Solving in the Middle School: Design and Construction with Simple Machines. *Journal of Pre-College Engineering Education Research (J-PEER)*, *3*(2), 43-55

Ertmer, P. A. (2010). Editor’s introduction. *The Interdisciplinary Journal of Problem-based Learning*, *4*(1), 4-5.

Ertmer, P. A., Schlosser, S. , Clase, K. , & Adedokun, O. (2013). The grand challenge: Helping teachers learn/teach cutting-edge science via a PBL approach. *Interdisciplinary Journal of Problem-based Learning*, *8*(1) doi.org/10.7771/1541-5015.1407.

Eitel, K., Hougham, J. R., Miller, B., Schon, J., & LaPaglia, K. (2013). Upload download: Empowering students through technology- enabled problem-based learning. Science Scope, *36*(7), 32-39.

Epstein, D., & Miller, R. T. (2011). Slow off the Mark: Elementary School Teachers and the Crisis in STEM Education. *Education Digest: Essential Readings Condensed for Quick Review*, *77*(1), 4-10.

Facione, P. A. (1990). Critical Thinking: A Statement of Expert Consensus for Purposes of Educational Assessment and Instruction. *Research Findings and Recommendations*.

Ferreira, M. M., & Trudel, A. R. (2012). The impact of problem-based learning (PBL) on student attitudes toward science, problem-Solving Skills, and sense of community in the classroom. *Journal of Classroom Interaction*, *47*(1), 23-30.

Fishbein, M. & Ajzen, I. (1975). *Belief, attitude, intention, and behavior: An introduction to theory and research*. MA: Addison-Wesley Publishing Company

Forrester, V. (2004). Problem-base learning: A problem with education? *Hong Kong Teachers' Centre Journal*, *3*, 48-55.

Fosnot, C. T. (1996). *Constructivism*: Theory, perspective, and practice. New York, NY: Teachers College Press.

Fox, R. (2001). Constructivism Examined. Oxford Review of Education, *27*(1), 23-35

Freiman, V., Beauchamp, J. B., Blain, S., Lirette-Pitre, N. L. P., & Fournier, H. (2011). Problem-based scenarios with laptops: an effective combination for cross-curricular learning in mathematics, science, and language. *World Journal on Educational Technology*, *3*(3), 136-152.

Frykholm, J., & Glasson, G. (2005). Connecting science and mathematics instruction: Pedagogical context knowledge for teachers. *School Science and Mathematics*, *105*(3), 127-141.

Furner, J. M., & Kumar, D. D. (2007). The mathematics and science integration argument: A stand for teacher education. *Eurasia Journal of Mathematics, Science & Technology Education*, *3*(3), 185-189.

Fortus, D., Krajcik, J., Dershimer, R. C., Marx, R. W., & Mamlok-Naaman, R. (2005). Design based science and real world problem solving. *International Journal of Science Education*, *27*(7), 855-879.

Gates, M., & Yan, W. (2001). *Relationship between constructivist teacher beliefs and instructional practices to students' mathematical achievement: Evidence from TIMMS.* Paper presented at the Annual Meeting of the American Educational Research Association, Seattle, WA (ERIC Document Reproduction Service No. ED456133).

Gallagher, S. A., Sher, B. T., Stepien, W. J., & Workman, D. (1995). Implementing problem-based learning in science classrooms. *School Science and mathematics*, *95*(3), 136-146.

Gijbels, D., Dochy, F., Van den Bossche, P., & Segers, M. (2005). Effects of problem-based learning: A meta-analysis from the angle of assessment. *Review of educational research*, *75*(1), 27-61.

Goonatilake, R., & Bachnak, R. A. (2012). Promoting Engineering Education among High School and Middle School Students. *Journal of STEM Education: Innovations and Research*, *13*(1), 15-21.

Goodnough, K., & Cashion, M. (2006). Exploring problem-based learning in the context of high school science: Design and implementation issues. *School Science and Mathematics*, *106*(7), 280-295.

Goodnough, K., & Nolan, B. (2008). Engaging elementary teachers' Pedagogical Content Knowledge: Adopting problem-based learning in the context of Science teaching and learning. *Canadian Journal of Science, Mathematics, and Technology Education*, *8*(3), 197-216.

Greenwald, N. L. (2000). Learning from problems. *Science Teacher*, *67*(4), 28-32.

Gursul, F., Keser, H., & Gulsecen, S. (2010). Adoption of PBL to Online Environments: Student's Perspectives. *International Journal of E-Adoption (IJEA)*, *2*(2), 19-34.

Halpern, D. F. (1998). Teaching critical thinking for transfer across domains: Disposition, skills, structure training, and metacognitive monitoring. *American Psychologist*, *53*(4), 449.

Handal, B., & Herrington, A. (2003). Mathematics teachers' beliefs and curriculum reform. *Mathematics Education Research Journal*, *15*(1), 59-69.

Hand, B., Treagust, D. F., & Vance, K. (1997). Student perceptions of the social constructivist classroom. *Science Education*, *81*(5), 561-575.

Hardin, C. (2009). Effectiveness and accountability of the inquiry-based methodology in middle school science. Retrieved May 19, 2014, from ERIC.

Harwood, J., & Rudnitsky, A. (2005). Learning about scientific inquiry through engineering. In *Proceedings of the 2005 ASEE Annual Conference, Portland, OR*.

Harlen, W. (1999). Effective teaching of science. *Investigating*, 1-111.

Haylock, D., & Thangata, F. (2007). In Key concepts in teaching primary mathematics. Retrieved June 8, 2014, from ERIC.

Heller, J. I., Daehler, K. R., Wong, N., Shinohara, M., & Miratrix, L. W. (2012). Differential effects of three professional development models on teacher knowledge and student achievement in elementary science. *Journal of Research in Science Teaching*, *49*(3), 333-362.

Henderson, J. (2009). Educating emerging entrepreneurs. *Education Update*, *51*(6). Retrieved July 10, 204 from, www.ascd.org/publications/newsletters/ education_update/jun09/vol51/num06/Educating_Emerging_Entrepreneurs.aspx.

Hernandez, P. R., Bodin, R., Elliott, J. W., Ibrahim, B., Rambo-Hernandez, K. E., Chen, T. W., & de Miranda, M. A. (2014). Connecting the STEM dots: measuring the effect of an integrated engineering design intervention. *International Journal of Technology and Design Education*, *24*(1), 107-120.

Hinkle, D. E., Wiersma, W., & Jurs, S. J. (2003). *Applied statistics for behavioral sciences* (2nd ed.). Boston, MA: Houghton Mifflin Company.

Hodson, D. (1999). Building a case for a sociocultural and inquiry-oriented view of science education. Journal of Science Education and Technology, *8*(3), 241-249.

Howe, A. C. (1996). Development of science concepts within a Vygotskian framework. *Science Education*, *80*(1), 35-51.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review*, *16*(3), 235-266.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kircshner, Sweller, and Clark (2006). *Educational Psychologist*, *42*(2), 99-107.

Hung, W. (2013). Problem-based learning: A learning environment for enhancing learning transfer. *New Directions for Adult and Continuing Education*, 137, 27-38

Inceoglu, M. M. (2010). Establishing a K-12 circuit design program. *IEEE Transaction of Education*, *53*(1), 152-157.

International Society for Technology in Education. (2008). National educational technology standards for teachers (2nd ed.). Washington, DC: Author.

International Technology and Engineering Educators Association. (2010). ITEA officially becomes ITEEA. Retrieved June 1, 2014 from http://www.iteaconnect.org/AboutITEEA/NameChange.pdf

Jadallah, E. (2000). Constructivist learning experiences for social studies education. *The Social Studies*, *91*(5), 221-225.

Jarvis, T., & Pell, A. (2004). Primary teachers' changing attitudes and cognition during a two-year science in service program and their effect on pupils. *International Journal of Science Education*, *26*(14), 1787-1811.

Jerzembek, G., & Murphy, S. (2013). A narrative review of problem-based learning with school-aged children: implementation and outcomes. *Educational Review*, *65*(2), 206-218.

Johns, R. A. (2012). What were they thinking? *The Science Teacher*, 79(3), 66-70.

Johnson, C. C. (2013). Conceptualizing integrated STEM education. *School Science and Mathematics*, *113*, 367–368.

Kalpana, T. (2014). A Constructivist perspective on teaching and learning: A conceptual framework. *International Research Journal of Social Sciences*, *3*(1), 27-29.

Kamii, C., & Ewing, J. K. (1996). Basing teaching on Piaget's constructivism. *Childhood Education*, *72*(5), 260-264.

Karatas, F. O., Micklos, A., & Bodner, G. M. (2011). Sixth-grade students' views of the nature of engineering and images of engineers. *Journal of Science Education and Technology*, *20*(2), 123-135.

Katehi, L., Pearson, G., & Feder, M. (2009). Engineering in K-12 education: Understanding the status and improving the prospects. Washington, DC: The National Academies Press.

Kelley, T. (2010). Staking the claim for the "T" in STEM. *Journal of Technology Studies, 36*(1), 2-11.

Kek, M. Y. C. A., & Huijser, H. (2011). The power of problem-based learning in developing critical thinking skills: preparing students for tomorrow's digital futures in today's classrooms. *Higher Education Research & Development*, *30*(3), 329-341.

Kepler. G., & Wicken, T. D. (2004). *Design and analysis: A researcher's handbook*. Upper Saddle River, NJ: Pearson Prentice Hall.

Kettler, T. (2014). Critical thinking skills among elementary school students: Comparing identified gifted and general education student performance. *Gifted Child Quarterly*, *58*(2), 127-136.

Klegeris, A., Bahniwal, M., & Hurren, H. (2013). Improvement in generic problem-solving abilities of students by use of tutor-less problem-based learning in a large classroom setting. *CBE-Life Sciences Education*, *12*(1), 73-79.

Kuder, G. F., & Richardson, M. W. (1937). The theory of the estimation of test reliability. *Psychometrika*, *2*(3), 151-160.

Kuenzi, J. J. (2008). Science, technology, engineering, and mathematics (STEM) education: Background, federal policy, and legislative action. Retrieved from, http://digitalcommons.unl.edu/crsdocs/35/.

Lachapelle, C. P., Sargianis, K., & Cunningham, C. M. (2013). Engineer it, learn it: science and engineering practices in action: Step into an elementary classroom to see what Next Generation Science standards practices look like. Science and Children, *51*(3) 70-76.

Lambros, A. (2002). *Problem-based learning in K-8 classrooms: A teacher's guide to implementation.* Thousand Oaks, CA: Sage Publication Ltd.

Lansiquot, R. D., Blake, R. A., Liou-Mark, J., & Dreyfuss, A.E. (2011). Interdisciplinary problem-solving to advance STEM success for all students. *Peer-Review*, 19-22

Leedy, P. D. & Ormrod, J. E. (2005). Practical research: Planning and design. Saddle River, NJ: Pearson Merrill Prentice Hall.

Lipton, E. B. (2005). President's message: advancing the tide of technology education. *Technology Teacher, 64*(6), 29-36.

Li, H. C. (2012). Implementing problem-based learning in a Taiwanese elementary classroom: a case study of challenges and strategies. *Research in Mathematics Education*, *14*(1), 89-90.

Lichtman, M. (2010). *Qualitative research in education: A user's guide*. (2nd ed.). Thousand Oaks, CA: Sage.

Liu, M., Hsieh, P., Cho, Y., & Schallert, D. (2006). Middle school students' self-efficacy, attitudes, and achievement in a computer-enhanced problem-based learning environment. *Journal of Interactive Learning Research*, *17*(3), 225-242.

Liu, C. H., & Matthews, R. (2005). Vygotsky's philosophy: Constructivism and its criticisms examined. *International Education Journal*, *6*(3), 386-399.

Liu, M., Wivagg, J., Geurtz, R., Lee, S. T., & Chang, H. M. (2012). Examining how middle school science teachers implement a multimedia-enriched problem-based learning environment. *Interdisciplinary Journal of Problem-based Learning*, *6*(2), 46-84.

Litowitz, L.S. (2008). A president's message with more questions than answers! *Technology Teacher*, *67*(6), 23-24.

Lottero-Perdue, P. S., Lovelidge, S., & Bowling, E. (2010) Engineering for all: Strategies for helping all students succeed in design process. *Science and Children*, *47*(7), 24-27.

Lou, S. J., Shih, R. C., Diez, C. R., & Tseng, K. H. (2011). The impact of problem-based learning strategies on STEM knowledge integration and attitudes: an exploratory study among female Taiwanese senior high school students. *International Journal of Technology and Design Education*, *21*(2), 195-215.

Masnick, A. M., Valenti, S. S., Cox, B. D., & Osman, C. J. (2010). A multidimensional scaling analysis of students' attitudes about science careers. *International Journal of Science Education*, *32*(5), 653-667.

McGee, J. R., Polly, D., & Wang, C. (2013). Guiding teachers in the use of a standards-based mathematics curriculum: Teacher perceptions and subsequent instructional practices after an intensive professional development program. School Science and Mathematics, *113*, 16-28.

Mehalik, M. M., Doppelt, Y., & Schunn, C. D. (2008). Middle-school science through design-based learning versus scripted inquiry: Better overall science concept learning and equity gap reduction. Journal of Engineering Education, *97*(1), 71–85.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation*. San Francisco, CA: Jossey-Bass.

Mertz, S. (2006). Problem-based learning. *Science Teacher*, *73*(8), 8.

Moore, T. J., & Smith, K. A. (2014). Advancing the state of the art of STEM integration. Journal of STEM Education, *15*(1), 5-10.

Morgan, G. A., & Griego, O. V. (1998). *Easy use and interpretation of SPSS for Windows: Answering research questions with statistics*. Mahwah, NJ: Psychology Press.

Mulnix, A. B., Vandergrift, E. VH. (2014). Tipping point in STEM education. Journal of College Science Teaching, 43(3), 14-16.

Murphy, T. P., & Mancini-Samuelson, G. J. (2012). Graduating STEM competent and confident teachers: The creation of a STEM certificate for elementary education Majors. *Journal of College Science Teaching*, *42*(2), 18-23.

Nadelson, L. S., Callahan, J., Pyke, P., Hay, A., Dance, M., & Pfiester, J. (2013). Teacher STEM perception and preparation: Inquiry-based STEM professional development for elementary teachers. *The Journal of Educational Research*, *106*(2), 157-168.

Nargundkar, S., Samaddar, S., & Mukhopadhyay, S. (2014). A guided problem-based learning (PBL) approach: Impact on critical thinking. *Decision Sciences Journal of Innovative Education*, *12*(2), 91-108.

Nathan, M. J., Atwood, A. K., Prevost, A., Phelps, L. A., & Tran, N. A. (2011). How professional development in Project Lead the Way changes high school STEM teachers' beliefs about engineering education. *Journal of Pre-College Engineering Education Research (J-PEER)*, *1*(1), 15-29.

National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). Reaching higher: *Common core state standards, mathematics*. Washington, DC: Authors.

National Research Council (2012). *A framework for K-12 education: Practices, core cutting concept, and core ideas*. Washington, D.C.: The National Academic Press.

Nayor. S. (1999). Constructivism in classroom: theory into practice. *Journal of Science Teacher Education. 10(2)*, 93-106.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, D.C.: The National Academies Press.

Norman, G. R., & Schmidt, H. G. (2000). Effectiveness of problem-based learning curricula: Theory, practice, and paper darts. *Medical education*, *34*(9), 721-728.

Nugent, G., Barker, B., Grandgenett, N., & Adamchuk, V. I. (2010). Impact of robotics and geospatial technology interventions on youth STEM learning and attitudes. *Journal of Research on Technology in Education*, *42*(4), 391-408.

Organization for Economic Co-Operation and Development. (2004). Learning for tomorrow's world: First results from PISA 2003. Paris: Author. Available at: http: //www.pisa.oecd.org/dataoecd/59/21/33917683.pdf.

Osborne, J., Simon, S., & Collins, S. Attitude towards science: A review of the literature and its implications. *International Journal of Science Education 25*(9), 1049-1079.

Paige, K., Lloyd, D., & Chartres, M. (2008). Moving towards transdisciplinary: an ecological sustainable focus for science and mathematics pre-service education in the primary/middle years. *Asia Pacific Journal of Teacher Education*, *36*(1), 19-33.

Palincsar, A. S. (1998). Social constructivist perspectives on teaching and learning. *Annual Review of* Psychology, *49*, 345-375.

Pallant, A., Pryputniewicz, S., Lee, H. S. (2012). Exploring the unknown. The Science Teacher, *79*(3), 60-65.

Papanastasiou, C., & Papanastasiou, E. C. (2004). Major influences on attitudes toward science. *Educational Research and Evaluation*, *10*(3), 239-257.

Paul, R., & Elder, L. (2009). *The miniature guide to critical thinking concepts & tools* Dillon Beach, CA: Foundation Critical Thinking.

Pepper, C. (2010). There'sa lot of learning going on but NOT much teaching!': student perceptions of Problem-Based Learning in science. *Higher Education Research & Development*, *29*(6), 693-707.

Peterson, R. F., & Treagust, D. F. (1998). Learning to teach primary science through problem-based learning. *Science Education*, *82*(2), 215-237.

Phillips, D. C. (1995). The good, the bad, and the ugly: The many faces of constructivism. *Educational researcher*, 5-12.

Piaget, J. (1964). Cognitive development in children: Development and learning. *Journal of Research in Science Teaching 2(3),* 176-186.

Potvin, P., & Hasni, A. (2014). Interest, motivation, and attitude towards science and technology at K-12 levels: a systematic review of 12 years of educational research. *Studies in Science Education*, *50*(1), 85-129.

Powell, K. C., & Kalina, C. J. (2009). Cognitive and social constructivism: Developing tools for an effective classroom. *Education*, *130*(2), 241-250.

Ramsey, K., & Baethe, B. (2013). The Keys to Future STEM Careers: Basic Skills, Critical Thinking, and Ethics. *International Journal for Professional Educators*, 26-33.

Ravitz, J. (2009). Introduction: Summarizing findings and looking ahead to a new generation of PBL research. *Interdisciplinary Journal of Problem-based Learning*, *3*(1), 4-11.

Ringwood, J. V., Monaghan, K., & Maloco, J. (2005). Teaching engineering design through Lego® Mindstorms™. *European Journal of Engineering Education*, *30*(1), 91-104.

Roberts, A. (2013). Stem is here. Now what? Technology & Engineering Teacher, 73 (1), 22-27.

Rockland, R., Bloom, D. S., Carpinelli, J., Burr-Alexander, L., Hirsch, L. S., & Kimmel, H. (2010). Advancing the "E" in K-12 STEM education. The Journal Of Technology Studies, *38* (1), 53-64.

Roehrig, G. H., & Luft, J. A. (2004). Research report: Constraints experienced by beginning secondary science teachers in implementing scientific inquiry lessons. *International Journal of Science Education*, *26*(1), 3-24.

Rogers, G. E. (2005). Pre-engineering's place in technology education and its effect on technological literacy as perceived by technology education. *Journal of Industrial Teacher Education, 42*(3), 6-22.

Roychoudhury, A. (2014). Connecting science to everyday experiences in preschool settings. Culture Studies of Science Education, *9*, 305–315

Sanders, M. (2009). STEM, STEM education, STEMmania. *Technology Teacher, 68*(4), 20-26.

Savery, J. R., & Duffy, T. M. (1995). Problem-based learning: An instructional model and its constructivist framework. *Educational technology*, *35*(5), 31-38.

Savery, J. R. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-based Learning*, *1*(1), 3.

Savin-Baden, M. (2001). The problem-based learning landscape. *Planet*, *4*, 4-6.

Saye, J. W. & Brush, T. (2002). Scaffolding critical reasoning about history and social issues in multimedia-supported learning environments. *Educational Technology Research and Development*, *50*(3), 77-96.

Schachter, R. (2011). Helping STEM Take Root. District Administration, *47*(4), 42-44.

Schoen, H. L., & Hirsch, C. R. (2003). Responding to calls for change in high school mathematics: Implications for collegiate mathematics. *American Mathematical Monthly*, 109-123.

Schettino, C. (2012). Teaching geometry through problem-based learning. *Mathematics Teacher*, *105*, 346-351.

Schmidt, H. G. (1993). Foundations of problem-based learning: Some explanatory notes. *Medical Education*, *27*, 422-432.

Schreiber, L. M., & Valle, B. E. (2013). Social constructivist teaching strategies in the small group classroom. *Small Group Research*, *44*(4), 395-411.

Schunk, D. H. (1991). Self-efficacy and academic motivation. *Educational psychologist*, *26*(3-4), 207-231.

Seimears, C. M., Graves, E., Schroyer, M. G., & Staver, J. (2012). How constructivist-based teaching influences students learning science. *The Educational Forum* *76*(2), 265-271.

Şendağ, S., & Ferhan Odabaşı, H. (2009). Effects of an online problem-based learning course on content knowledge acquisition and critical thinking skills. *Computers & Education*, *53*(1), 132-141.

Shepardson, D. P. (1999). Learning science in a first grade science activity: A Vygotskian perspective. *Science Education*, *83*(5), 621-638.

Silva, E. (2009). Measuring skills for 21st-century learning. *Phi Delta Kappan*, *90*(9), 630-634.

Simons, K. D., Klein, J. D., & Brush, T. R. (2004). Instructional strategies utilized during the implementation of a hypermedia, problem-based learning environment: A case study. *Journal of Interactive Learning Research*, *15*(3), 213-233.

Simons, K. D., & Klein, J. D. (2007). The impact of scaffolding and student achievement levels in a problem-based learning environment. *Instructional Science*, *35*(1), 41-72.

Siversten. L. M. (1993). *Transforming ideas for teaching and learning science. A guide for elementary science education: state of the art*. Washington, DC: Office of Educational Reach and Improvement.

Shulman, L.S 1986. Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Smagorinsky, P. (1995). The social construction of data: Methodological problems of investigating learning in the zone of proximal development. *Review of Educational Research*, *65*(3), 191-212.

Smith, J., & Karr-Kidwell, P. J. (2000). The interdisciplinary curriculum: A Literary Review and a Manual for Administrators and Teachers.

Soares, N. (2011). Increased student interest and proficiency in STEM topics needed. *SEEN: South Eastern Education Network, 13*(3*),* 98-99.

Sockalingam, N., Rotgans, J., & Schmidt, H. G. (2011). Student and tutor perceptions on attributes of effective problems in problem-based learning. *Higher Education*, *62*(1), 1-16.

Spencer, B. R. & Rogers, G. E. (2006). The nomenclature dilemma facing technology education. *Journal of Industrial Teacher Education, 43*(1), 91-99.

Starkman, N. (2007). Problem solvers. *T H E Journal (Technological Horizons In Education)*, *34*(10), 35-42.

Staver, J. R. (1998). Constructivism: Sound theory for explicating the practice of science and science teaching. *Journal of Research in Science Teaching*, *35*(5), 501-520.

Stepien, W., & Gallagher, S. (1993). Problem-based learning: As authentic as it gets. *Educational leadership*, *50*, 25-25.

Stepien, W. J., & Pyke, S. L. (1997). Designing Problem-Based Learning Units. *Journal for the Education of the Gifted*, *20*(4), 380-400.

Stern, D., & Stearns, R. (2006). *Combining academia and career-technical courses to make college an option for more students: Evidence and challenges*. Berkeley: The University of California.

Stigler, J. W., & Hiebert, J. (2009). Closing the teaching gap. *Phi Delta Kappan*, *91*(3), 32-37.

Stinson, K., Harkness, S. S., Meyer, H., & Stallworth, J. (2009). Mathematics and science integration: Models and characterizations. *School Science and Mathematics*, *109*(3), 153-161.

Stipek, D. J., Givvin, K. B., Salmon, J. M., & MacGyvers, V. L. (2001). Teachers' beliefs and practices related to mathematics instruction. *Teaching and teacher education*, *17*(2), 213-226.

Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research (J-PEER)*, *2*(1), 23-34.

Stohlmann, M., Moore, T. J., McClelland, J., & Roehrig, G. H. (2011). Impressions of a Middle Grades STEM Integration Program. *Middle School Journal, 43*(1), 32-40.

Strobel, J., & van Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms. *Interdisciplinary Journal of Problem-based Learning*, *3*(1), 44-58.

Sullivan, F. R. (2008). Robotics and science literacy: Thinking skills, science process skills, and systems understanding. *Journal of Research in Science Teaching*, *45*(3), 373-394.

Swartz, R., Costa, A., Beyer, B., Reagan, R., & Kallick, B. (2007). *Thinking based learning*. Norwood, MA: Christopher-Gordon.

Tarhan, L., Ayar-Kayali, H., Urek, R. O., & Acar, B. (2008). Problem-based learning in 9th grade chemistry class:'Intermolecular forces'. *Research in Science Education*, *38*(3), 285-300.

Tarmizi, R. A., & Bayat, S. (2012). Collaborative problem-based learning in mathematics: A cognitive load perspective. *Procedia-Social and Behavioral Sciences*, *32*, 344-350.

Tomlinson, C. A. (2009). Intersections between differentiation and literacy instruction: Shared principles worth sharing. *New England Reading Association Journal*, *45*(1), 28-33.

Tseng, K. H., Chang, C. C., Lou, S. J., & Chen, W. P. (2013). Attitudes towards science, technology, engineering, and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education*, *23*(1), 87-102.

The White House (2009). *President Obama launches "educate to innovate" campaign for excellence in science, technology, engineering & math (STEM) education*. Retrieved May 29, 2012 from http://http://www.whitehouse.gov/the-press-office/president-obama-launches-educate-innovate-campaign-excellence-science-technology-en

Trevey, M. T. (2008) STEM education. State News, 51(9), 34-35.

Torp, L., & Sage, S. (1998). *Problems as possibilities: Problem-based learning for K-12 education*. Alexandria, VA: Association for Supervision and Curriculum.

Tuzun, O. Y. (2008). Preservice elementary teachers' beliefs about science teaching. *Journal of Science Teacher Education*, 19, 183-204.

Tytler, R., Waldrip, B., & Griffiths, M. (2002). Talking to effective teachers of primary science. *Investigating*, *18*(4), 11-15.

VanTassel-Baska, J., Bracken, B., Feng, A., & Brown, E. (2009). A longitudinal study of enhancing critical thinking and reading comprehension in Title I classrooms. *Journal for the Education of the Gifted, 33*, 7-37.

VanTassel-Baska, J., & Stambaugh, T. (2009). Project Athena: A pathway to advanced literacy development for children of poverty. *Gifted Child Today*, *29*(2), 58-63.

Vernon, D. T., & Blake, R. L. (1993). Does problem-based learning work? A meta-analysis of evaluative research. *Academic medicine*, *68*(7), 550-63.

Vygotsky, L. S. (1978). Mind and society: The development of higher mental processes. Cambridge, MA: Harvard University Press

Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research (J-PEER)*, *1*(2), 2, 1-13.

Walker, D., & Lambert, L. (1995). Learning and leading theory: A century in the making. In L. Lambert, D. Walker, D. P. Zimmerman, J. E. Cooper, M. D. Lambert, M. E. Gardner, & P. J. F. Slack (Eds.), *The constructivist leader,* 1-27. NY, New York: Teachers College Press.

Wadsworth, B.J. (2004). Piaget's theory of cognition and affective development. Boston, MA: Anyn & Bacon.

Watson, J. (2001). Social constructivism in the classroom. *Support for Learning*, *16*(3), 140-147.

Wendell, B. K., & Rogers, C. (2013). Engineering design-based science, science content performance, and science attitudes in elementary school. *Journal of Engineering Education*, *102*(4), 513-540.

Wieman, C. (2012). Applying new research to improve science education. *Issues in Science and Technology*, *29*(1). 25-32.

Wertsch, J. V. (1985). *Vygotsky and the social formation of mind*. Cambridge, MA: Harvard University Press.

Wheland, E. R., Donovan, W. J., Dukes, J. T., Qammar, H. K., Smith, G. A., & Williams, B. L. (2013). Green Action through Education: A Model for Fostering Positive Attitudes about STEM. *Journal of College Science Teaching*, *42*(3), 46-51.

Wilkins, J. L. M. (2008). The relationship among elementary teachers' content knowledge, attitudes, beliefs, and practices. *Journal of Mathematics Teacher Education*, *11*(2), 139-164).

Willingham, D. T. (2008). Critical thinking: Why is it so hard to teach? *Arts Education Policy Review, 109,* 21-32.

Wong, K. K. H., & Day, J. R. (2009). A comparative study of problem-based and lecture-based learning in junior secondary school science. *Research in Science Education*, *39*(5), 625-642.

Wrightsman, L. S. (1977). Social psychology. Monterey, CA: Brooks/Cole Publishing.

Yu, u, C. H. (2001, April). An introduction to computing and interpreting Cronbach Coefficient Alpha in SAS. In *Proceedings of 26th SAS User Group International Conference* (pp. 22-25).

Zacharia, Z., & Barton, A. C. (2004). Urban middle school students' attitudes toward a defined science. *Science Education*, *88*(2), 197-222.

Zhang, M., Parker, J., Eberhardt, J., & Passalacqua, S. (2011). "What's so terrible about swallowing an apple seed?" Problem-based learning in kindergarten. *Journal of science education and technology*, *20*(5), 468-481.

CURRICULUM VITA

Graduate College
University of Nevada, Las Vegas

Abeera P. Rehmat

Degrees:

B.S. Computer Science,
St. John's University, Jamaica, NY

M.S. Elementary Education
Nova Southeastern University, Fort Lauderdale, FL

Special Awards and Honors:

Member of Golden Key Honor Society

National Technology Leadership Initiative (NTLI) Award Finalist

Honorable mention at UNLV Graduate and Professional Student Association (GPSA) annual research forum

Recipient, Graduate and Professional Student Association Travel Grant
University of Nevada, Las Vegas

Publications:

Rehmat, A. P., & Bailey, J. M. (2014). Technology integration into a science classroom: Preservice teachers' perceptions. *Journal of Science Education and Technology*, *23,* (744-755).

Nussbaum, E. M., Owens, M. C., Sinatra, G., M., Rehmat, A.P., Cordova, J. R., Vesco, J. M., Ahmad, S., Harris, Jr. F. C., & Dascalu, S., M. (in print). Losing the Lake: Simulations to promote gains in student knowledge and interest about climate change. *International Journal of Environmental and Science Education*.

Nussbaum, E. M., Cordova, J. R., & Rehmat, A. P. (in review). Refutation texts for fffective climate change education. *Journal of Geoscience Education*.

Rehmat, A.P., Bailey, J. M., & Owens, M.C. (in preparation). Engineering awareness among high school science, mathematics and technology teachers. *Journal of Engineering Education*.

Owens, M. C., Bollu, P., & Rehmat, A. P. (2015, February) – *What is a research question? A collaborative action research approach to aiding postdoctoral residents in research study development.* Poster Presented at the Ethnographic and Qualitative Research Conference in Las Vegas, NV.

Rehmat, A. P., Owens, M. C., & Bailey, J. M. (2015, January). *The earlier the better: Teacher Beliefs about Design, Engineering, and Technology Instruction*, poster presented at the Association for Science Teacher Education Conference in Portland, OR.

Rehmat, A. P., Bailey, J. M. (2014, April). *Engineering Awareness among high school science,mathematics and technology Teachers*, paper presented at the International Conference of the National Association of Research in Science Teaching, Pittsburg, PA.

Deniz, H., Adibelli, Rehmat, A. P., & Topcu, M.S. (2014, April). *Conceptions of teaching among Turkish and American K-8 science teachers*, paper presented at the International Conference of the National Association of Research in Science Teaching, Pittsburg, PA.

Cordova, J. R., Nussbaum, E. M. Owens, M. C., & Rehmat, A. P. (2013, August). *Fostering interest in learning more about climate change through a computer simulation game.* Paper presented at the biannual meeting of the European Association for Research on Learning and Instruction, Munich, Germany.

Nussbaum, E. M., Owens, M. C., Rehmat, A. P., & Cordova, J. R. (June, 2013). *Towards collaborative argumentation in "Losing the Lake."* Poster presented at the International Conference on Computer-Supported Collaborative Learning, Madison, WI.

Nussbaum, E. M., Owens, M. C., Cordova, J. R., Rehmat, A. P., & Sinatra, G. M. (2013, March). *Simulations to promote student knowledge and interest gains in environmental science and climate change.* Paper presented at the 24th International Conference of the Society for Information Technology and Teacher Education, New Orleans, LA.

Rehmat, A. P., & Bailey, J. M. (2013, January). *Technology integration into a science classroom: Preservice teachers' perceptions*, paper presented at Association for Science Teacher Education 2013 International Conference, Charleston, SC.

Bailey, J. M., Rehmat, A. P., Lombardi, D., & Keppelmann, E. (2012, March). *Developing science teacher leaders through long-term professional development: A cross-case analysis of four teachers*, paper presented at the 85th International Conference of the National Association of Research in Science Teaching, Indianapolis, IN.

Dissertation Title: Engineering the Path to Higher-Order Thinking Skills in Elementary: A Problem-Based Learning Approach to STEM Integration

Dissertation Examination Committee:
Co-Chairperson, Hasan Deniz, Ph.D.
Co-Chairperson, Kendall Hartley, Ph.D.
Committee Member, Danielle B. Brown, Ph.D.
Graduate Faculty Representative, Brendan J. O'Toole, Ph.D.