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Building Engineering Awareness: Problem-Based Learning Approach for STEM Integration

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ABSTRACT

Educators in the twenty-first century 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. This study sought to investigate the impact of problem-based learning on students' content knowledge and critical thinking towards STEM. This study employed a quasi-experimental repeated measure design. Instruments such as STEM content assessments and a standardized critical thinking test were employed for data collection. Analysis was conducted using a mixed repeated measure between-within subject analysis of variance (ANOVA). The results revealed a significant difference (p <. 05) between problem-based learning and traditional learning groups in regard to their content knowledge and critical thinking skills.

Keywords: problem-based learning, STEM education, engineering education, science education

Science, technology, engineering, and mathematics (STEM) education is critical for our future advancement (Becker & Park, 2011; Caprile, Palmen, Sanz, & Dente, 2015). This is in part due to a decline in the number of undergraduate degrees earned in STEM fields (National Academies of Science, Engineering, and Medicine, 2018; Sanders, 2009). In fact, a report from the advocacy group New American Economy (2017) indicated that the "United States has a persistent and dramatic shortage of STEM workers" (p.1) causing the demand for more professionals in STEM areas to increase. As highlighted by the U.S. Committee on STEM Education, "The jobs of the future are STEM jobs," (National Science and Technology Council, 2013, p. vi) with STEM competencies required within and beyond STEM occupations (English, King & Smeed, 2017).

In an effort to address the current status of STEM, various institutions and organizations have created curricula for use in pre-college education. For example, the Engineering is Elementary curriculum integrates engineering with science (Cunningham & Hester, 2007) and the PictureSTEM curriculum assimilates STEM and literacy (Moore & Tank, 2014). Furthermore, the Common Core Standards for language arts and mathematics (National Governors Association, 2010) and the Next Generation Science Standards (NGSS Lead States, 2013) have been developed to change the current status of STEM.

The unification of STEM content areas has the potential to provide students with the knowledge and skills they need to become successful well-informed individuals (English, Hudson, & Dawes, 2013; Sanders, 2009). This integration can improve students' academic achievement and develop students' interest in STEM-related fields, while promoting engineering education (Stinson, Harkness, Meyer, & Stallworth, 2009). Furthermore, learning in this manner can provide students with an all-inclusive meaningful experience, stimulating the learner to engage in or relate to real-world experiences (Furner & Kumar, 2007; English, 2016; Moore & Smith, 2014; Roberts, 2013; Stohlmann, Moore, McClelland & Roehrig, 2011). Robert (2013) asserts the interconnectedness of STEM fields can incite an innovative way to teach and develop students' understanding in science, leading to a STEM literate society.

Consequently, this study aims to promote STEM integration by using an integrated curriculum facilitated through problem-based learning to augment students' content knowledge understanding and critical thinking.

Problem-Based Learning and Social Constructivism

Problem-based learning (PBL) is a student-centered approach in which students acquire knowledge through collaboration and problem-solving (Hmelo-Silver, 2004; Norman & Schmidt, 2000). In a PBL classroom the teacher takes the role

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of a facilitator that guides the students through the investigative process rather than serving as a leader (Liu, Wivagg, Geurtz, Lee & Chang, 2012). Barrows (2000) described PBL as a total approach to education, one that has the potential to replace traditional lecture-based teaching to foster students' conceptual knowledge and higher-order thinking skills.

PBL supports Vygotsky's (1978) sociocultural theory which emphasizes cultural and language-based interactions (Powell & Kalina, 2009). Social constructivism promotes social interaction among students in the classroom, while allowing them to apply their critical thinking process in learning (Powell & Kalina, 2009). Vygotsky (1978) claimed that all individual construction is mediated by social factors, and learning does not just take place within the individual. Rather the learner is an active and social contributor to the learning environment versus being a mere receiver of diffused knowledge.

Vygotsky's sociocultural theory (Li, 2012; Savery & Duffy, 1995) has many overlapping similarities with the characteristics of PBL. In PBL, knowledge is attained through engagement by undertaking a complex problem (Savery, 2006). The ill-structured problem stimulates dialogue and argumentation (Hmelo-Silver, 2004) fostering discourse, which are important for a social constructivist classroom as it enables communication between the learners and/or the facilitator (Bächtold, 2013). The facilitator provides guidance via scaffolding, modeling, and questions. Likewise, in sociocultural theory, the teacher or an advanced peer plays the same role: to provide guidance so the student can reach a new conceptual understanding. These similarities between Vygotskian theory and PBL clearly indicates that social constructivism is the underlying educational theory and framework for a PBL pedagogy.

Effectiveness of PBL in Education

PBL originated in the medical field in the late 1960s because traditional education (e.g., lectures, rote memorization) acquired by medical students had little effect on their performance during residency (Barrows, 2000; Servant-Miklos, 2018). Empirical studies, including meta-analyses, have been conducted to explore the benefits of PBL primarily among adult learners (Albanese & Mitchell, 1993; Strobel & Van Barneveld, 2009). Findings from these studies have been mixed. Many results have been positive, indicating that PBL is superior to traditional methods in several of the domains examined (e.g., long-term knowledge retention and knowledge recall) (Albanese & Mitchell, 1993; Strobel & Van Barneveld, 2009). For instance, studies conducted in medical education found that PBL groups score lower than traditional education on short-term basic knowledge examinations but have a better long-term retention (Dochy, Segers Van den Bossche, & Gijbels, 2003; Strobel & Van Barneveld, 2009). However, Berkson (1993) concluded that a PBL curricula graduate is no different from his or her counterpart in traditional curricula.

PBL has also been adopted by several disciplines across K-12 settings (Hmelo-Silver, 2004; Jezembek & Murphy, 2013; Ravitz, 2009; Savery, 2006). In fact, The Center for Problem-Based Learning at the Illinois Mathematics and Science Academy was the first to introduce and endorse PBL in a K-12 environment. Since then, PBL has been employed in various content areas in elementary, middle, and high school education (Merritt, Lee, Rillero, & Kinach, 2017; Trinter, Moon, & Brighton, 2015; Zhang, Parker, Eberhardt, & Passalacqua, 2011). Jezembek and Murphy (2013) conducted a meta-analysis and reviewed empirical studies involving school-aged children. Their finding supported PBL's positive influence on students' academic and personal development. However, several of the studies were conducted at the secondary level. Thus, more research is needed to determine the impact of PBL on student learning across educational settings (Rico & Ertmer, 2015; Merritt, et al., 2017).

PBL has also been shown to increase students' critical thinking skills, problem-solving skills, achievement, and decision-making skills (Barrell, 2007). For this study, critical thinking is defined 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" (Facione, 1990, p. 2). Critical thinking requires the learning environment to be deeply rooted in developing skills as the learning outcome (Kek & Huijser, 2011). Therefore, critical thinking skills are best when taught in an integrated manner, rather than a stand-alone topic (Kek & Huijser, 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. Although PBL has shown positive effects on students critical thinking, many of these studies have been conducted with adult learners (Nargundkar, Samaddar, & Mukhopadhyay, 2014), and empirical studies exploring the effect of critical thinking on students in K-12 are limited (Araz & Sungur, 2007; Klegeris, Bahniwal, & Hurren, 2013). Therefore, there is a need to further investigate the impact of PBL on students critical thinking, specifically to explore if STEM-integrated PBL can foster critical thinking.

Problem-Based Learning for STEM Integration

PBL has been employed to teach a wide range of academic levels and areas, due to the impact it can have on learning (Jezembek & Murphy, 2013; Merritt et al., 2017; Trinter et al., 2015). Meanwhile, STEM integration can provide students with rich interdisciplinary learning experiences that can enrich content knowledge and cultivate higher-order thinking skills (English et al., 2017; Moore & Tank, 2014; Roberts, 2013). Hence, STEM-integrated curricula taught using PBL can kindle an interest in STEM disciplines, enhance students' creativity, and arouse curiosity in young children. This fusion can encourage students to apply cross-disciplinary knowledge in real-world context (Roberts, 2013). Furthermore, the integration of STEM using PBL can develop collaborative skills and encourage independency while motivating students to become lifelong learners. However, limited studies have been conducted to examine the effect of PBL coupled with a STEM-integrated curriculum for elementary students (Dischino, DeLaura, Donnelly, Massa, & Hanes, 2011; Duran & Şendağ, 2012). This study aims to fill the void in the literature by using an integrated curriculum facilitated through PBL while investigating the effect of an integrated STEM curriculum implemented through PBL on fourth-grade students' content knowledge and critical thinking skills. This study is guided by the following research questions:

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?

Hypotheses

PBL is an all-inclusive hands-on/minds-on approach to comprehend the content being presented in the classroom. Considering the audience is elementary students, the fourth-grade students that participate in the PBL 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 PBL group will show greater gains in critical thinking skills than fourth-grade students that participate in traditional learning group. This will be evident because PBL and STEM integration will promote active engagement during the problem-solving process.

Methods

Research Design

The study employed quasi-experimental and repeated measures design. The four classrooms were evenly and randomly assigned to a control group and a treatment group. The control group had a total of 46 students (n = 46) and the treatment group had a total of 52 students (n = 52), though the sample in two groups varied due to students not fully participating in the study. However, all classes were equally diverse in regard to demographics and achievement level. The control group was referred to as the traditional learning group (TL) and the treatment group (PBL) was the problem-based learning group.

Participants and Setting

The population in 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 whom 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 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 racial 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 the fourth-grade population is 48 males (n = 48) and 50 females (n = 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 in this study was a science specialist and taught science to all fourth-grade classes involved in this study. She 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. She had over five years of teaching experience in K-5 during the study.

This study took place at a tuition-free public charter school situated in a suburban neighborhood. Science in this school was taught as a special subject similar to art, music, and library rather than as 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.). Monday and Tuesday science classes (class 1 & 2) were assigned to TL groups, while Wednesday and Thursday science classes (class 3 & 4) were assigned to PBL groups. Each class had science once a week on their respective day. During the study, both groups were taught the same STEM-integrated content.

Instruments

Content Knowledge Assessments

There were two content knowledge assessments (CA1 & CA2) created for this study, one for each unit. The questions on each of the content knowledge assessments comprised of multiple choice, true/false, and open-ended constructed response questions. There were between 25 to 27 questions, with three to five 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 and functions of the trout's structure, life cycle, and habitat. In the math content area, geometry concepts (rays and line segment relationships), symmetry, temperature, and measurements were addressed. In engineering and technology, the test covered concepts in design, materials, and search tools. The first content assessment (CA1) had 27 questions in total: eighteen multiple choice, six true and false, and four constructed response items. The total score students could attain on CA1 was 36 points, which comprised of 23 points for multiple choice and true/false (1 pt. each) and 12 points for the four constructed responses (3 pts. ea.).

In the second content assessment (CA2), questions covered land formations, plate tectonics, geology of the area, and natural disasters for science. In math, questions on measurements and word problems to calculate distance were included, in addition to engineering and technology questions on tools and practices. The second content knowledge assessment (CA2) had a total of 25 questions: seventeen multiple choice, six true/false, and three short answer questions. The total score students could attain on CA2 was 32 points which comprised 23 points for multiple choice and true/false (1 pt. each) and 9 points for the three constructed responses (3 pts. ea.).

A scoring rubric was created for the constructed-response items. There were two types of content knowledge scores: 1) a score for the selected responses (MCQ/TF) 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 by two coders independently and then interrater reliability was determined. The interrater reliability was 80%. Any disagreements between the coders' coding was discussed until an agreement was formed.

The Criterion Referenced Tests in math and science laid the foundation for formulating the questions on 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. 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), which indicate 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. The test was specifically designed for elementary students, focusing on grades third to fifth, and has been used with gifted and general education student populations (Bracken et al., 2003; Kettler, 2014). The TCT is theoretically based on Facione (1990) Delphi panel's definition of critical thinking. The TCT consists of 45 items arranged across 10 scenarios. Each scenario is followed by three to six items; items are multiple-choice format with four answer choices per item. Since the test is intended to assess critical thinking, 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 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).

Procedures

The participating fourth-graders had science once a week for 55 minutes; the duration of this study was 16 weeks. 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.

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. Each of the unit plans addressed the NGSS Standards (NGSS Lead States, 2013), the Common Core Mathematics Standards, and Computer and Technology Standards.

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.

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 area, plate tectonics, and possible natural disasters that can affect 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.

The study was divided into three phases: Pre-Instruction Phase, Instruction Phase, and Post-Instruction Phase.

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 Critical Thinking Test (TCTpre).

Instruction Phase

The instruction phase began with both groups (TL & PBL) completing content knowledge assessment one (CA1pre) for activity one, week one of the instruction phase. This assessment was taken during week three 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, 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 and colleagues (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 Chart together as a team. The first question on the chart was, "What do you know?", followed by, "What do you need to know?", and finally, the last question, "How can you find out what you need to know?" As soon as all the teams had compiled their ideas, a class discussion was held with the teacher regarding the current problem. The teacher went through each column of the Need to Know chart and recorded each team's responses on the white board. The Need to Know chart helped to guide the learning and served as an organization tool for the students.

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 first conceptualizing, 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., the 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 minute detailed presentation to the entire class where they shared their model, identified the materials they utilized for their prototype, and explained 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 1.

Table 1. 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, for the first two weeks students completed the demographic form and TCTpre. Next, they completed unit plan 1 for 6 weeks (including CA1post), then unit plan 2 for 6 weeks (including CA2post). Lastly, they completed TCTpost (Total weeks = 16).

Control group (TL). The TL group's instruction varied from the PBL group. 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 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 the teacher 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 2.

Table 2. 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, for the first two weeks students completed the demographic form, and TCTpre. Next, they completed unit plan 1 for 6 weeks (including CA1post), then unit plan 2 for 6 weeks (including CA2post). Lastly, they completed and TCTpost (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 test of critical thinking (TCTpost) during weeks 15 and 16.

Analyses

Quantitative analysis was conducted for the two research questions. These questions involved mixed repeated measure between-within subject analysis of variance (ANOVA). The independent groups were PBL and 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) and the critical thinking test (TCT) measured at each time period (pre/post).

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

Results

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 across two-time periods (CA1pre – CA1post & CA2pre – CA2post). The findings of CA1 and CA2 revealed an increase in students' mean scores from pretest to posttest in both the PBL group and TL group (Table 3). 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.

The mixed repeated measure between-within subject analysis of variance (ANOVA) analysis for CA1 provided evidence that the interaction between time periods (pre-post) and teaching method was statistically significant, Wilks' $\lambda = .85$, $F(1, 96) = 16.88$, $p < .001$, $\eta p2 = .15$. There was a substantial main effect for time (pre to post), Wilks' $\lambda = .05$, $F(1, 96) = 1708.40$, $p < .001$, $\eta p2 = .95$, 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, $F(1, 96) = 22.94$, $p < .001$, $\eta p2 = .19$ (large effect size) (Cohen, 1988), suggesting a difference in the effectiveness of the two teaching methods 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' $\lambda = .63$, $F(1, 96) = 57.33$, $p < .001$, $\eta p2 = .37$. There was also a large main effect for time, Wilks' $\lambda = .09$, $F(1, 96) = 951.10$, $p < .001$, $\eta p2 = .91$, 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, $F(1, 96) = 24.29$, $p = .02$, $\eta p2 = .20$, (large effect size) (Cohen, 1988), suggesting a difference in the effectiveness of the two teaching methods on students' content knowledge assessment (CA2).

Impact of PBL on Critical Thinking Skills

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 the 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). The findings showed that the mean scores of students in the both PBL group and TL group increased from pretest to posttest (Table 3). 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.

The mixed repeated measure between-within subject analysis of variance (ANOVA) analysis provided evidence that the interaction between time and teaching method was statistically significant, Wilks' $\lambda = .34$, $F(1, 96) = 190.66$, $p < .001$, $\eta p2 = .67$. There was a substantial main effect (Cohen, 1988) for time, Wilks' $\lambda = .85$, $F(1, 96) = 533.39$, $p < .001$, $\eta p2 = .88$, 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, $F(1, 96) = 131.23$, $p < .001$, $\eta p2 = .58$, suggesting a significant difference in the effectiveness of the two teaching methods on students' critical thinking skills.

Table 3. Pre/Post Content Knowledge Assessment and Critical Thinking Scores for TL and PBL Groups

Groups	Pretest			Posttest	
	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
	Pretest TCT			Posttest TCT	
TL	16.11	3.34		21.37	6.12
PBL	16.29	2.48		37.19	5.03
Total	16.20	2.90		29.77	9.68

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

Discussion

Impact of PBL on STEM Content Knowledge

Although the evidence is limited and varies in regard to the effect PBL can have on learners' content knowledge (Strobel & Van Barneveld, 2009; Jerzembek & Murphy, 2013), the results from this study suggest that PBL instructional methodology was the driving mechanism for the enhanced content knowledge exhibited by the PBL group. The PBL method allowed 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 (Barell, 2007; Hmelo-Silver, 2004). Students in the PBL group spent the majority of their time generating ideas and developing action plans for assessing necessary information they needed to solve the problem. The continuous process stimulated 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 students collected information, they learned the science content and learned about various materials for designing, as well as applied mathematics skills to solve the problems. Furthermore, PBL methodology allowed them to distinguish between 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 an important component for test-taking.

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, the 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 PBL group 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 (Azar & Sungur, 2007). In the PBL environment, unlike in the TL environment, students were 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.

The change in student content knowledge can also be attributed to their shift in attitude towards STEM. A connection was found between students' attitude and their knowledge assessment. Space limitations preclude a full treatment of the attitude data in the current study. However, the results indicate that PBL prompted active engagement in learning, while also encouraging them to be reflective and creative. This runs counter to the typical classroom setting. This constant interaction with the authentic knowledge base and application of multiple skills over several weeks encouraged students to develop a deeper interest in STEM content. This also triggered a shift towards a more positive attitude in STEM education, which potentially contributed to the improved performance on the knowledge assessment (Ferreira & Trudel, 2012).

Moreover, the problem scenario was hands-on, in addition to minds-on. Students in the PBL had to actually design a prototype as their solution. The "E" in this STEM-integrated activity required students to applying content knowledge and cognitive processes to design, analyze, and revise, making the entire process of design integrative and iterative in nature, which helped to foster students' content knowledge (Brophy, Klein, Portsmore & Rogers, 2008).

Impact of PBL on Critical Thinking Skills

The change in the PBL groups' critical thinking skills in this study is attributed to the PBL problem and content integration. Though research with young children is limited, this finding is similar to other studies (Araz & Sungur, 2007; Kettler, 2014; Klegeris et al., 2013; 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 were real-world situated and provided 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. From this stemmed multiple solutions, encouraging them to use their imagination and creativity to find a possible solution. Through this hunt for a solution to given problems, students have the potential to develop critical thinking skills, problem-solving skills, and decision-making skills (Barell, 2007; Barrows, 2000; 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.

Conclusion

PBL is a useful learning tool for STEM integration as indicated by the outcomes of this study. Although further research in this area is necessary, this study provides a practical relevance for improving the quality of teaching and learning in our schooling system. This approach can 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 (Furner & Kumar, 2007; Kettler, 2014). Studies have found PBL to be an effective methodology that can be applied to various settings and content areas (Araz & Sungur, 2007). Thus, it is necessary to consider pedagogies, such as PBL, that can endorse integrated STEM 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.

Limitations

Limitations are a characteristic of all forms of educational research and this study is no exception. The first limitation of this study relates to the participants of this study and to what extent the results are generalizable. The participants are a representation of elementary students in several suburban southwest U.S. school districts (i.e., predominately Caucasian). Therefore, generalization of these results outside of this population should be done with caution.

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

Future Suggestions

This study adds to literature and offers new knowledge regarding how an assimilated STEM curriculum facilitated through PBL can amplify students' critical thinking skills and content understanding. The current study can be expanded to include a longitudinal study of this specific PBL experience. This will provide insight on whether the PBL approach continues to complement their learning with increased critical thinking.

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.

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