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The Effects of STEM PBL on Students' Mathematical and Scientific Vocabulary Knowledge

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Abstract

Vocabulary is at the surface level of language usage; thus, students need to develop mathematical and scientific vocabulary to be able to explicitly communicate their mathematical and scientific reasoning with others. The National Council of Teachers of Mathematics (NCTM) and the National Science Teachers Association (NSTA) have both created communication standards within mathematics and science disciplines. In the present study, science, technology, engineering, and mathematics (STEM) project based learning (PBL) methods were utilized during a summer camp in 2013 to encourage interest in and grow the knowledge of students in the STEM disciplines. The participants (N = 53; 18 female, 35 male, 5 Asian, 6 African American, 12 White, and 30 Hispanic) were 8th grade students. The paired-sample t tests' results showed that the model of STEM PBL instruction elicited a statistically significant ($p < 0.05$) improvement in the mathematical and scientific vocabulary knowledge of students with the *Cohen's d* effect size of 0.62 and 0.84 respectively. STEM PBL could be a beneficial instructional method concerning vocabulary mastery for students in science and mathematics classes.

Key words: STEM PBL, Mathematics and Science vocabulary.

Introduction

Every day people communicate using words and expressions that may have various meanings. In order to fluently communicate with one another, people must have a shared understanding of the meaning of the words they use. Otherwise, the communication could fall short of conveying the intended message. Individuals who spoke entirely different languages could have great difficulty verbally communicating because of the differences in words used for the same object. Clarity in language facilitates communication and could be the building block to greater understanding, particularly in the fields of science and mathematics.

Developing vocabulary in the science and mathematics classrooms was much like learning a foreign language. When a new word was introduced to a student, the word had to be taught and the meaning explained. Once this was achieved, students could communicate meaningfully with their peers and teachers. The development of a common vocabulary within a subject was vital so that individuals could communicate coherently and efficiently with one another. Development of vocabulary in the content areas of mathematics and science was important for students to be able to communicate and more completely understand the topics they were learning. Vocabulary was often built on previous vocabulary, with one word perhaps representing a single process that required understanding of several other content specific vocabulary words. For instance, the word "photosynthesis" represented the process of a plant producing energy from the sun, but within that process words such as "chlorophyll," "organelles," and "chloroplasts" needed to be understood. Determining the best methods of teaching vocabulary to students was critical.

In 2003, the National Council of Teachers of Mathematics (NCTM) emphasized the importance of language in mathematics classrooms by placing a broad range of mathematical communication goals into NCTM's recommended standards. These goals included, but were not limited to, students being able to: a) organize their mathematical thinking, b) communicate in the mathematics classroom with others (teachers and peers), c) evaluate different mathematical solution strategies, and d) use mathematical language explicitly. However,

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achieving these goals in mathematics classrooms was not an easy job. Thompson and Rubenstein (2000) noted that using mathematical language was often a challenge for students due to several reasons. One of the common reasons was that students lacked mathematical vocabulary development. Previous studies found that students have difficulty communicating their own mathematical thoughts and understanding the meaning of mathematical texts due to their lack of mathematical vocabulary development (Rubenstein, 2007; Kenney et al., 2005). According to Miller (1993), "without an understanding of the vocabulary that is used routinely in mathematics instruction, textbooks, and word problems, students are handicapped in their efforts to learn mathematics" (p. 312). Different approaches had been taken to determine the best method of increasing student mathematical vocabulary.

There were several challenges to learning mathematics vocabulary. When students were able to identify a relationship between new vocabulary words and their prior knowledge, the process of learning new vocabulary was easier and avoided more misconceptions (Ashlock, 2006). However, Cirillo, Bruna, and Herbal-Eisenmann (2010) noted that the mathematical vocabulary students learned during instruction was mostly limited to the classroom and students did not have an opportunity to apply the words in their daily lives. The inability to apply the mathematical terminology in a real world setting inherently limited the opportunities for learning reinforcement. In addition to the lack of real world application, there were several other challenges students had to overcome in order to develop a fluent and accurate understanding of mathematics vocabulary, including: a) some mathematical words were shared with everyday English but sometimes with distinct meanings, b) some mathematical terms were used only in mathematics, c) some mathematical words had multiple meaning depending on context, d) some mathematical words had the same sound as everyday English words, e) some words had modifiers that may change their meaning, f) some words were also used in science, and g) some words were learned in pairs (Rubenstein, 2013; Thompson & Rubenstein, 2000). Teachers in the mathematics classroom should allow students to explore, investigate, and explain mathematical vocabulary when they encounter new mathematical words and terms (Steele, 1999).

Science Vocabulary

Vocabulary mastery was also important to success in the science classroom. Learning science included learning the proper terminology or vocabulary for the science discipline being taught. The National Science Teachers Association (NSTA, 2014) developed the Next Generation Science Standards in which students were required to communicate design ideas, solutions, and scientific and technical information through oral presentations or written forms. These different means of communicating in a professional and meaningful way were to develop the skills that scientists and engineers would need in their careers. These methods of communication also showed greater fluency with new, content-specific vocabulary than simply filling in the blank or matching tasks. A questionnaire given by Cook and Tulip (1992) to science teachers to determine what features science teachers felt were important in a textbook found that a glossary (vocabulary) ranked 12th out of 40 with a mean of 4.46 (features were ranked from 1 to 5 with 5 being "very important"). Science vocabulary mastery was important to developing proficiency in the sciences.

Science vocabulary, much like the mathematics vocabulary previously discussed, was both critical and challenging for a student to master. One of the challenges associated with learning science vocabulary was the fact that comprehension of a new word depended greatly on understanding a variety of other vocabulary words (Fisher, Grant, & Frey, 2009). Within a single word there may be "stored descriptions and explanations of ideas, events, or patterns" (Yore, Craig, & Maguire, 1998, p. 34). A student that struggled with basic science vocabulary found the mastery of more advanced topics difficult because mastery required synthesizing multiple science vocabulary words to understand complex systems and processes (Cohen, 2012). For instance, a student that did not comprehend the meaning behind the word "evaporation" would not be able to fully understand the complex system of the water cycle, of which "evaporation" is only a part. In addition to the compounding nature of science vocabulary, the extensive number of science vocabulary words presented a challenge. Within textbooks there could exist hundreds or even thousands of new science words (Groves, 1995). This large number of new science vocabulary that existed in textbooks could present students with an overwhelming task as they tried to master all of them. The fact that science textbooks presented new vocabulary words and then used those very words to present even greater concepts, coupled with the extensive nature of science vocabulary lists, made mastery of science words critical and challenging for students.

Methods of Teaching Vocabulary

To enable students to overcome the obstacles to learning new, content-specific vocabulary, researchers have suggested several instructional models for mathematics and science. For this study, two broad categories had been identified for methods of instruction to increase science and mathematics vocabulary. The first method was through contextual learning, and the second concentrated on more direct methods.

Contextual instructional methods enabled students to witness the processes and actions behind the vocabulary, allowing students to create a mental image. NCTM (1989; 1991) and Miller and Gildea (1987) encouraged using a contextual mathematical instructional model, thus allowing students to observe how mathematical words were used in a mathematical context. Contextual learning could help students to develop images of the word meanings, thereby creating a deeper understanding of the term. Several different imagery-based interventions could be utilized to help students form mental images of the science concepts being taught, thus making the meanings of the associated vocabulary words more easily retained and recalled (Cohen & Johnson, 2011; Cohen, 2012).

Direct teaching methods focused on in-class activity that was less hands-on than contextual learning but still required students to engage in learning in non-traditional ways. Vacca and Vacca (1996) noted that important mathematical words needed to be taught by direct instruction. Methods that have been employed to teach science vocabulary have included using text cards, word lists, graphic organizers, and word games (Carrier, 2011). Developing a strong vocabulary foundation at a young age and continuing to foster new vocabulary mastery through literacy-based interventions could be beneficial in learning new vocabulary (Cohen, 2012).

Monroe and Orme (2002) found that neither contextual nor direct vocabulary teaching alone was sufficient to develop students' mathematical vocabulary, but these two instructional methods should be complementary to each other. Within a lesson, vocabulary must be thoughtfully integrated in such a manner that conceptual learning was not trumped by simple memorization of new terminology (Bay-Williams & Livers, 2009) utilizing the appropriate methods available. This perspective, that the best method of teaching vocabulary was the combination of direct and contextual learning, was the theoretical basis of the present study.

The cohesion of findings in previous research provided the framework for the present study. Learning vocabulary beyond the rote memorization of terms and definitions required a combination of direct teaching in which an instructor gave the meanings of words and allowed students the opportunity to develop an understanding of the processes and purposes that each vocabulary word represents (Monroe & Orme, 2002). By working in a context, students were able to associate images and actions with terms and reinforce their understanding of definitions. Instructional methods that provide students with the opportunity to learn definitions of words associated with a context and develop imagery related to each term would benefit students' vocabulary retention and understanding. Because project based learning (PBL) includes features of both contextual and direct teaching and allows students to create mental images associated with scientific vocabulary, the present study attempted to determine how STEM PBL (see the conceptual framework in Figure 1) affected students' mathematical and scientific vocabulary knowledge.

Figure 1. *Conceptual Framework*

STEM Project Based Learning (STEM PBL)

Understanding how students learn best could aid the teacher in determining how to teach vocabulary words. Project based learning was an instructional method driven by student inquiry and directed by teacher guidance (Bell, 2010). Projects were created by students and shared with their peers, and outcomes of PBL implementation included greater and deeper understanding of topics, higher-level reading, and an increase in motivation. PBL challenged students with authentic tasks in real world contexts to develop and use their knowledge of different subjects (Thomas, 2000). Science, technology, engineering, and mathematics (STEM) PBL was the application of PBL methods in one of the STEM subjects or in an interdisciplinary manner (Corlu, Capraro, & Capraro, 2014). Introducing new vocabulary words through STEM PBL helped students to connect new vocabulary words with imagery in a concrete way (Bicer, Navruz, Capraro, & Capraro, 2014; Bicer, et al., 2015). When a student was involved with the concept in a hands-on way and used that new vocabulary word in action, the student was better prepared to write technical information using proper terminology or vocabulary (Bicer, Capraro, & Capraro, 2013; Bicer, Capraro, & Capraro, 2014). The use of PBL for increasing vocabulary mastery in both mathematics and science could be promising due to the contextual application of the hands-on activity and the potential for students to develop imagery connecting vocabulary words to the meaningful actions and processes taking place, as well as by providing opportunities for teachers to give direction and guidance.
The present study aimed to answer the following question:

(1) How does engagement in a STEM PBL activity affect students' mathematical and scientific vocabulary development?
(2) How does engagement in a STEM PBL activity affect students' scientific conceptual understanding?

Method

Participants

The participants (N = 53) were 8th grade students who attended a summer camp in 2013. Of the 53 students, 18 were female and 35 were male. The student group was comprised of 5 Asian, 6 African American, 12 White, and 30 Hispanic students.

Intervention

The intervention took place during a two-week summer camp designed by a STEM center at a Tier 1 research university. Throughout the summer camp, students were involved in activities that fostered their mathematical and scientific vocabulary knowledge through STEM PBL. One of the projects students engaged in during the camp was an egg drop PBL that consisted of designing and testing a unique parachute that would land an egg safely on the ground. These parachute activities met four days per week for one hour and 15 minutes per day and included 10 hours per week of independent study including, but not limited to, gathering materials, creating hypotheses, and journal writing.

Vocabulary Assessment

The study involved 24 academic vocabulary words, of which 12 were mathematics words and 12 were science words. Students learned and repeatedly used these terms during the egg drop PBL activity. The mathematical vocabulary words and terms were: pi, Pythagorean Theorem, constant, regular polygon, diameter, variable, angle, hexagon, surface area, polygon, circle, and length segment. These mathematical vocabularies were selected as being more problematic from the list provided by Rubenstein (2013) and Thompson and Rubenstein (2000). The science vocabulary words and terms were: velocity, gravity, energy, force, kinetic energy, potential energy, momentum, air resistance, thermal energy, terminal velocity, friction, and the law of conservation. These science vocabularies were selected based on the science standards from the Texas Education Agency (TEA). Students were required to use the selected words to effectively communicate their mathematics and science reasoning during the PBL with their peers and teachers. Pre and post-test examinations were administered to assess student vocabulary knowledge of the words that were emphasized during the PBL. These exams consisted of definitions and a word bank of vocabulary words from which to select the term that appropriately matched each definition. Each correct match was assessed as a score of one point with a possible total score of 12 points per subject. Another test that included true-false statements was administered in order to assess whether students increased their scientific conceptual understanding. This test (see Table 1) was utilized to determine if learning through a STEM PBL activity also had an effect on students' conceptual understanding. Each correct answer was assessed as a score of 1 point with a possible total of 11 points.

Table 1. True-False Statements Test

1) T-F	Energy is greatest in the egg drop vehicle just before it hits the ground.
2) T-F	Before the egg starts to fall all of its energy is in the form of kinetic energy.
3) T-F	Momentum decreases as the egg falls.
4) T-F	Momentum depends on both the speed of the object and its mass.
5) T-F	The force of gravity acting on the egg is greater than the force of air resistance.
6) T-F	The force of gravity gets larger the more mass it has.
7) T-F	The air resistance on an object depends on the mass of the object.
8) T-F	Gravity and Momentum both stay the same the whole time the egg falls.
9) T-F	Potential energy increases the closer an object is to the ground.
10) T-F	Kinetic Energy increases as the speed increases.
11) T-F	Kinetic energy starts out at 0.

Analysis

The Statistical Package for Social Science (SPSS) version 17.0 (2008) was used to run the analysis on 53 written responses. There were no missing data, and this sample size was adequate to detect differences between two dependent means (paired *t* tests) at the 5% statistical significance level (Faul, Erdfelder, Lang, & Buchner, 2007). Cohen's d effect sizes and confidence intervals were provided to examine the practical importance of the present study.

Results

The paired-sample *t* test results showed that STEM PBL instruction elicited a statistically significant improvement in the mathematical vocabulary knowledge of students, $p < 0.05$ with the effect size of *Cohen's d* = 0.62. Results also showed that the model of STEM PBL instruction statistically significantly increased students' science vocabulary knowledge, $p < 0.05$, *Cohen's d* = 0.84. Students' pre-science and pre-mathematics scores were reexamined to eliminate the scores already perfect in the pre-test. The paired-sample t tests were also used to test how students' scientific conceptual understandings changed after participating in STEM PBL. The results associated with the true-false science concepts test indicated that students increased their mean score of scientific conceptual understanding; however, this increase (see Figure 1) on their posttest compared to their pretest was not statistically significant, $p > 0.05$, *Cohen's d* = 0.14.

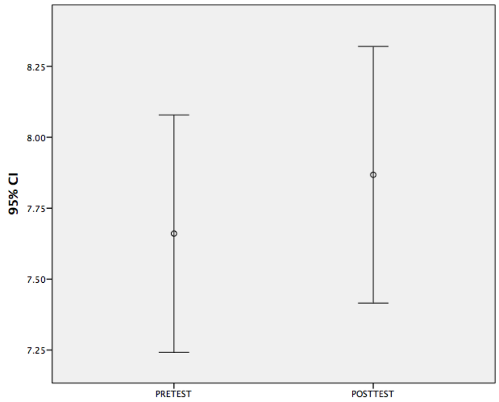

Figure 1. *A 95% Confidence Interval for Students Scientific Conceptual Understanding*

Discussion

Vocabulary development begins at a young age and continues throughout a person's life. A single word can indicate various and complex meanings. This reality makes vocabulary mastery critical, especially when students begin to study more complex mathematics and science topics. A word may indicate an entire process or theorem and have differing meanings depending on the context. Shortcomings in these specialized vocabularies lead to challenges when trying to communicate with peers and teachers (Miller, 1993; Rubenstein, 2007; Kenney et al., 2005). NCTM (2003) and NSTA (2014) have called for an increase in communication skills within mathematics and science studies. Ensuring that students are able to share and explain ideas and solutions fluently with peers and teachers could be facilitated by improved student vocabulary in the content areas of mathematics and science.

The purpose of this study was to test whether participating in STEM PBL activities affects students' mathematics and science vocabulary knowledge. STEM PBL integrates direct teaching with contextual learning and allows students to develop mental images and make connections between content-specific vocabulary and activities taking place in the lab or classroom. An important aspect of STEM PBL is that students share their solutions with their peers, thus strengthening their ability to communicate using terms that are content specific (Thomas, 2000). As these communication skills are developed, the vocabulary is internalized through the hands-on activities and interactions of the students in their classes. Students are given the opportunity to see visuals and create mental images of scientific processes associated with vocabulary words. These images can help students retain vocabulary meanings and enhance students' recall of definitions (Cohen, 2012).

The present study indicates favorable outcomes when implementing STEM PBL. More can be done to determine the value of STEM PBL implementation. Studies evaluating the effectiveness of STEM PBL during the regular school day would be informative, considering the fact that this particular study took place during a summer camp. Research with a larger group of students would also yield more interesting results. Further studies can be conducted to give greater insight into the benefits of STEM PBL as a means of vocabulary and conceptual learning.

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