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Intersecting the Past and the Future of Science and Mathematics Integration

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Oklahoma City, Oklahoma

Margaret J. Mohr-Schroeder

Jonathan Thomas

Editors

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INTERSECTING THE PAST AND THE FUTURE OF SCIENCE AND MATHEMATICS INTEGRATION

Special thanks to

Maureen Cavalcanti and Emma Chadd, University of Kentucky Graduate Students, for all of their hard work on the proceedings.

School Science and Mathematics Association

Founded in 1901

The School Science and Mathematics Association [SSMA] is an inclusive professional community of researchers and teachers who promote research, scholarship, and practice that improves school science and mathematics and advances the integration of science and mathematics.

SSMA began in 1901 but has undergone several name changes over the years. The Association, which began in Chicago, was first named the Central Association of Physics Teachers with C. H. Smith named as President. In 1902, the Association became the Central Association of Science and Mathematics Teachers (CASMT) and C. H. Smith continued as President. July 18, 1928 marked the formal incorporation of CASMT in the State of Illinois. On December 8, 1970, the Association changed its name to School Science and Mathematics Association. Now the organizational name aligned with the title of the journal and embraced the national and international status the organization had managed for many years. Throughout its entire history, the Association has served as a sounding board and enabler for numerous related organizations (e.g., Pennsylvania Science Teachers Association and the National Council of Teachers of Mathematics).

SSMA focuses on promoting research-based innovations related to K-16 teacher preparation and continued professional enhancement in science and mathematics. Target audiences include higher education faculty members, K-16 school leaders and K-16 classroom teachers.

Four goals define the activities and products of the School Science and Mathematics Association:

- Building and sustaining a community of teachers, researchers, scientists, and mathematicians
- Advancing knowledge through research in science and mathematics education and their integration
- Informing practice through the dissemination of scholarly works in and across science and mathematics
- Influencing policy in science and mathematics education at local, state, and national levels

In Memory of John Park

SSMA lost a long-time member and friend this year. John who had a long history of involvement in SSMA was serving as Past-President at the time of his passing. Recognizing SSMA as one of his professional homes, John joined as a 'life member' early in his academic career. John was actively involved in SSMA, a continual presence at the conventions, conducting insightful presentations as well as encouraging and engaging colleagues.

John's long-time service to SSMA included: Convention Program Chair, multiple terms on the Board of Directors, SSMJ Reviewer, SSMA President from 2012-2014 and Past President. John had a national reputation as a teacher-educator and served in leadership roles within the profession beyond SSMA. John was a beloved SSMA member and will truly be missed by all.

In honor of John and his interest in encouraging new researchers, SSMA established the John Park Graduate Student Award and awarded the first recipients at the 2015 convention.

PREFACE

These proceedings are a written record of some of the research and instructional innovations presented at the 114th Annual Meeting of the School Science and Mathematics Association held in Oklahoma City, Oklahoma, October 29 – 31, 2015. The theme for the conference is *Intersecting the Past and the Future of Science and Mathematics Integration*.

The blinded, peer reviewed proceedings includes 13 papers regarding instructional innovations and research. The acceptance rate for the proceedings was 57%. Papers are presented in alphabetical order.

We would like to thank Maureen Cavalcanti and Emma Chadd for their dedication to the technical details of putting together this document. We are pleased to present these Proceedings as an important resource for the mathematics, science, and STEM education community.

Margaret J. Mohr-Schroeder
Jonathan N. Thomas
Co-Editors

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VOLUME 2

UNDERSTANDING THE NATURE OF SCIENCE THROUGH INTEGRATING THE HISTORY OF SCIENCE

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Understanding the Nature of Science (NOS) is perceived as critical to the development of students' scientific literacy. Integrating the History of Science (HOS) in an inquiry-context may facilitate more adequate understanding of NOS and the processes of science itself. This study investigated how middle school students' perceptions and understanding of NOS were altered after participating in a weeklong inquiry-based experience that was framed within an authentic earth science HOS context. Students' initial views of NOS were mixed with many students holding inadequate understandings. After the intervention, several students' views were altered. Implications for classroom teaching are addressed.

Introduction

As our society becomes increasingly more technological, the need for scientifically literate citizens and science proficiency has become ever more critical (Schweingruber, Duschl, & Shouse, 2007). An important component of scientific literacy is the development of an adequate understanding of the Nature of Science (NOS) (Duschl, 2008). Additionally, an essential component of NOS is understanding the historical context of the current concepts taught in science (Allchin, 2013; Bybee, Powell, Ellis, Giese, & Singleton, 1991). By experiencing the explicit integration of the History of Science (HOS), students may learn science in a more meaningful manner and may gain a greater understanding of the true nature of science. Explicit instruction of NOS through the integration of HOS in an authentic experience should address the primary tenants of NOS, scientific literacy and scientific inquiry (Lederman, 2007).

Objectives of the Study

Typically, students' understandings of NOS contain misconceptions even if students learned through inquiry methods (J. S. Lederman & Lederman, 2005; Schwartz, Lederman, & Crawford, 2004). Without an authentic inquiry learning experience, such as in a HOS integrated 5E lesson that plans for explicitly focusing on the NOS, students may walk away from these experiences holding on to those misconceptions with no greater understanding of NOS (Schwartz et al., 2004). Thus, the objective of this study was to determine how integrating HOS in an earth science context effects student understanding of NOS. The research questions that guided this study were: What are middle school students' understandings of NOS at the beginning of a HOS integrated earth science unit? And How do middle school students' understandings of NOS change after participation in a weeklong HOS integrated 5E earth science unit?

Related Literature

Without an adequate understanding of NOS, science learners construct an image of science consisting of isolated facts devoid of any context relative to the learner (Schwartz et al., 2004). Therefore, the definition of NOS proposed by Lederman and Lederman (2005) was utilized in this study. This definition postulates the following seven aspects of the NOS: scientific knowledge is (a) tentative, (b) subjective, (c) empirically based, (d) depends on creativity and imagination, (e) socially embedded, (f) emphasizes a distinction between inferences and observations, and (g) distinguishes between scientific theory and law.

Implementation of high quality HOS science curriculum with an explicit NOS focus (Allchin, 2011) must go beyond the casual mention of a great scientist's name, when he or she was born or died, lists of accomplishments, or the basic account of the scientific discovery (Klopfer, 1969). It must provide a historical science context for student discourse to occur which leads to explicit reflection on the aspects of NOS inherent within each HOS case (Allchin, 2011, 2013; Guney & Seker, 2012). It must facilitate learning that is stimulating in a way that students begin to understand the philosophical and cultural implications of scientific knowledge (Guerra et al., 2012; Matthews, 1992). It must serve as a guide, and also as a "source of inspiration" to educational curriculum design that provides the opportunity to improve the teaching and learning of NOS (Seroglou, Koumaras, & Tselfes, 1998). The curriculum developed and utilized in this study was designed to address these needs.

Few NOS and HOS studies to date have focused on either middle school students and or earth science concepts (Abd-El-Khalick & Lederman, 2000; Akerson et al., 2009; Guerra et al., 2012; J. S. Lederman & Lederman, 2005; Solbes & Traver, 2003; Wandersee, 1986). This study seeks to add a new dimension to the existing body of scientific knowledge regarding the development of student understanding of NOS. This study will attempt to investigate middle school students' understanding of NOS using a historical context grounded within a historical earth science controversy.

Methodology

A pre-/post-test research design was utilized in this study to investigate the effect of an authentic HOS integrated earth science 5E instructional unit (Bybee, 2013) on middle school students' understanding of NOS. The research design is based on designs used in previous studies investigating NOS, HOS, and student understanding of the aspects related to each domain (see Abd-El-Khalick and Lederman, 2000; Akerson, Abd-El-Khalick, & Lederman, 2000; Lederman & Lederman, 2005; Schwartz, Lederman, & Crawford, 2004). Qualitative and quantitative methods were utilized to describe the students' views of NOS and to investigate changes in students' views of NOS.

Seven 8th grade students (four male and three female; 13-14 years of age) from one middle school in a large suburban district in a midwestern state participated over a period of five consecutive instructional days. These students volunteered to participate in the study and were randomly selected from a larger non-graded elective class to form a smaller temporary class for the purpose of this research study. Students completed the VNOS-D2 before and after experiencing the HOS integrated 5E unit, they were observed during participation in the unit, and they were interviewed at the end of the research study.

The instructional unit (see Table 1), which was designed specifically for this study by the lead author, followed the 5E instructional model (Bybee, 2013). The context of the unit focused on glacier theory and how glaciers shape Earth's surface. HOS elements were integrated in the latter part of the unit through role-play in a historic scientific controversy. The entire 5E unit

Table 1

HOS Integrated 5E Earth Science Unit Overview

Instructional Time	Unit Activities
10 minutes	Engage: Students were given a scenario in which they had to make inferences from the evidence at hand and propose plausible theories using the Claims, Evidence, Reasoning (CER) model to explain what occurred.
35-45 minutes	Explore: Students participated in a simulation showing glacial movement and its results. Students viewed a real glacier flow time-lapse video over a 5-year period.
10 minutes	Explain: Students created a t-chart explaining the similarities and the differences in their glacier model and real glacier movements. Students examined the evidence for modern day Glacial Theory.
45 minutes	Elaborate: Students investigated original glacial evidence from the 1830's. Students "travelled" along with Louis Agassiz on one of his field expeditions into the Alps. Students played the role of William Buckland, a Geologist in the early 1800's, who was unsure about glacial theory. Students analyzed the competing theories (glacial theory, diluvial theory, and drift theory) and tested them against the available evidence at hand.*
35-45 minutes	Evaluate: Students composed a speech to the British Association for the Advancement of Science to explain why they either supported or rejected Glacial Theory and cited evidence for or against the theory.*

Note. * The Elaborate and Evaluate activities integrated HOS.

required three, 50-minute periods of instruction. Although all seven aspects of NOS were inherent in the unit, understanding the empirical NOS and the difference between observation and inference were an explicit focus throughout the unit.

The VNOS-D2 (Verifying the Nature of Science version D2; Lederman, 2007), a twelve-item open-ended survey, was used to assess students' beliefs and perceptions of NOS both pre and post HOS intervention. All students were purposefully selected to participate in a short interview after the data collection was complete (N. G. Lederman et al., 2002). Along with open-ended pre/post surveys and interviews, students were observed during the classroom instruction by a trained outside observer.

The student survey responses, interviews, and observations were analyzed using a constant comparative method (Glaser & Strauss, 1967). For the purpose of these proceedings, attention will be focused on the pre/post survey responses. Participant (n = 7) survey responses were coded into overarching categories (n = 7) based on the utilized NOS framework and analyzed using a NOS rubric created using Lederman's NOS framework (2007) and the NSTA position statement on NOS (National Science Teachers Association, 2000). Each response was independently evaluated by two outside reviewers along with the primary researcher and given a rating of an inadequate, adequate, or informed view in each category of the NOS framework (see Akerson et al., 2009). The three researchers met to compare ratings and reconcile any discrepancies so to establish consensus and reliability before reviewing post intervention responses. Once all ratings were in agreement, a pre/post intervention NOS profile was generated for each student and compared to determine any changes in the students' views and understanding of NOS.

Results and Discussion

At the onset of the study, students demonstrated different patterns of understanding for each of the seven aspects of NOS (see Table 2). Most students had at least an adequate understanding that science is *empirically based* (6 of 7) and that scientific knowledge is *tentative* (5 of 7). Whereas, all students (7 of 7) had an inadequate understanding of the difference between *scientific theory and scientific law*, and all but one student (Student 1) had an inadequate understanding of the difference between *observation and inference*. Of the possible 49 views of NOS (seven students X seven NOS aspects), 28 views were rated as inadequate, 20 as adequate, and only 1 as informed. One student (Student 1) had at least an adequate understanding for all NOS aspects except for the difference between *theory and law*.

Conversely, one student (Student 7) had an inadequate understanding for all seven NOS aspects.

Overall, all students demonstrated an increased understanding of NOS in one or more aspects. One student (Student 6) was only able to participate in the first two days of the intervention and did not participate in the HOS integrated component. Thus, post-intervention data for this student were not analyzed with the other students' post-intervention data. It should be noted that this student only deepened understanding in the *creative/imaginative* NOS aspect. All students (6 of 6) had at least an adequate understanding that science is *empirically based* and that scientific knowledge is *tentative*. Most students (5 of 6) held at least an adequate view of the *creative/imaginative* aspect of NOS. Whereas, only two students (Students 1 and 5) enhanced their understanding of the difference between *theory and law*, and only three students improved their understanding of the difference between *observation and inference*. Of the possible 42 views of NOS (six students X seven NOS aspects), only 10 views were rated as inadequate, 22 as adequate, and 10 as informed. These post intervention ratings reflect a more enhanced understanding; 13 aspects were enhanced from inadequate to adequate and nine aspects were enhanced from adequate to informed. Based on the overall findings, the authentic 5E HOS integrated earth science unit had a positive effect on student understanding of the NOS to some degree.

Table 2

Changes in Students' Understanding of Nature of Science (NOS)

Student	NOS Aspect						
	Tentative	Subjective	Empirical	Creative/ Imaginative	Socio-Cultural	Observation vs. Inference	Theory vs. Law
1	A-If	A-If	If-If	A-If	A-If	A-A	Ia-A
2	A-A	Ia-A	A-A	A-A	A-If	Ia-A	Ia-Ia
3	A-If	A-A	A-If	Ia-Ia	A-A	Ia-Ia	Ia-Ia
4	Ia-A	Ia-Ia	A-A	A-If	Ia-Ia	Ia-A	Ia-Ia
5	A-A	Ia-A	A-If	Ia-A	A-A	Ia-A	Ia-A
6*	A-A	Ia-Ia	A-A	Ia-A	Ia-Ia	Ia-Ia	Ia-Ia
7	Ia-A	Ia-Ia	Ia-A	Ia-A	Ia-A	Ia-Ia	Ia-Ia

Note – Pre-Post; Ia=Inadequate A=Adequate If=Informed; * Post-intervention data were not analyzed due to student missing the HOS earth science component of the unit.

The findings from the onset of this study are supported by other research findings (Khishfe, 2008; Khishfe & Abd-El-Khalick, 2002; Kim & McKinney, 2007; Smith, Maclin, Houghton, & Hennessey, 2000) in that many middle school students hold mixed views toward NOS aspects. Considering the philosophical stance toward inquiry science at the school site and across the district, it is not surprising that all but one student held at least an adequate view toward the empirical NOS and all but two students held an adequate view toward the tentative NOS. What is surprising is that only one student held an adequate view of the difference between observation and inference and no students understood the difference between a scientific theory and a scientific law.

The data suggest that most students enhanced their views of NOS as a result of the HOS 5E earth science instructional unit; however, there were several NOS aspects that remained difficult for students to modify. At the onset of the study, it was believed that understanding the difference between observation and inference and the empirical NOS would be the NOS aspects that would increase the most as these were an explicit focus in the intervention. However, these two aspects only saw moderate change. In order for students to gain a better understanding of the difference between observations and inferences and the empirical NOS, continued explicit instruction regarding these NOS aspects may be required (Khishfe & Abd-El-Khalick, 2002). The most tenacious NOS aspect for these students to modify was distinguishing between scientific theory and scientific law. Most students hold the misconception that theories progress into laws when enough people believe them or enough evidence is generated to support that theory (Abd-El-Khalick & BouJaoude, 1997; Allchin, 2013; Buaraphan, 2012; N. G. Lederman et al., 2002). These tenacious NOS aspects may require more explicit coverage over a longer period of time or repeated reflective experiences with the particular NOS aspect (Akerson et al., 2009; Khishfe & Abd-El-Khalick, 2002; J. S. Lederman & Lederman, 2005).

Although this study contained several limitations, such as small sample size, lack of a control group and random sampling, and readability of the survey, the data and interpretations presented in this study are representative of findings in previous studies using similar study frameworks relying on pre/post NOS profiles with small sample sizes and/or the exclusion of a control group for a comparison (Abd-El-Khalick & Lederman, 2000; Akerson et al., 2009; Guney & Seker, 2012; J. S. Lederman & Lederman, 2005; Schwartz & Lederman, 2002; Schwartz et al., 2004; Wandersee, 1986).

Implications

We concur with others (Abd-El-Khalick & Lederman, 2000) that it is highly unlikely that views of NOS can be effectively modified during a few hours, days, or weeks. Nonetheless, several students did improve their understandings of NOS when experiencing an authentic 5E HOS integrated unit. The student (Student 6) that showed the least advancement of understanding of NOS, was not able to participate in the entire intervention for unforeseen reasons. This student only participated in the first two days of the authentic 5E earth science unit in which the students used scaled models to simulate glacial ice flow down valleys. The student did not take part in HOS components of the authentic 5E HOS integrated unit. This might possibly point to the effectiveness of HOS integration at helping students to gain a better understanding of NOS. Science educators can utilize the HOS as a powerful learning opportunity for science students to gain a more complete understanding of the NOS.

Effective HOS integration used as a context for explicit NOS coverage has shown in previous studies to have similar positive impacts on student understanding of NOS (Guney & Seker, 2012; Maurines & Beaufils, 2012; Solbes & Traver, 2003). When students gain experience with NOS using HOS integrated learning, they have the opportunity to make connections between the rich history of scientific endeavors and discoveries to the present state of science. They may begin to create critical connections to STEM, and more importantly, they may see themselves as making positive contributions to the future of STEM.

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USING SELF-STUDY TO NAVIGATE CONFLICT AND TENSIONS IN A SCIENCE COURSE FOR PRESERVICE TEACHERS

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This paper describes a conflict, which arose in a teacher education course, and the use of self-study to reflect upon and adjust the teacher educator's (TE) practice in response to the resulting tensions in his practice. The course objectives were to increase preservice teachers' science content knowledge and to develop their skills in identifying and synthesizing content knowledge from a teacher's perspective. The paper provides a theoretical framework grounding the research in professional identity development; describes the self-study methodology employed to examine and modify the TE's practice; and shares findings, which contribute to the pedagogy of science teacher education.

Introduction

In a teacher education program (TEP), preservice teachers (PSTs) face unique challenges in their education courses. In such courses, the PSTs must think about their coursework from the perspective of a teacher and begin developing their own professional identity. The teacher educator (TE) must acknowledge and support this professional identity development by turning the challenges of TEP courses into instructional opportunities through which the PSTs can grow.

The present paper describes challenges that occurred for PSTs who were enrolled in my (first author) science content course for elementary teachers as well as the resulting tensions that arose in my practice. The pedagogical approach I used in the course required the PSTs to investigate, in groups, a series of scientific phenomena (e.g., earthquakes) and to present the results of their investigation in both written and oral formats. Conflict arose during one such investigation/presentation cycle when I perceived the PSTs' work as insufficient, rife with oversimplifications and misunderstandings, and representative of little effort. The PSTs considered my reaction to their work as overly critical and unnecessary. Rather than believing my own perceptions to be accurate, overlooking the conflict, and continuing with the curriculum schedule, I chose to employ self-study to expose my assumptions and the underlying sources of the conflict and evaluate the effectiveness of the pedagogical approach used to navigate the identified tensions. The paper provides a theoretical framework grounding the research in professional identity development; describes the self-study methodology

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employed to examine and modify my practice; and shares findings, which contribute to the pedagogy of science teacher education.

Objectives of the Study

The objectives of the present study were to explore the underlying sources of the conflict; expose the resulting tensions in my practice; modify my practice in response to the conflict and tensions; and evaluate the effectiveness of the modifications. Specifically, I addressed the following overarching question and two sub-questions:

How can I use reflection activities to navigate the conflict?

(1) What were the underlying sources of the conflict?

(2) In what ways did my change in pedagogical approach help resolve the conflict?

Theoretical Framework

As PSTs advance through a TEP, they progress through stages on their way to developing their professional teacher identities (the ultimate goal of a TEP). The present study examines this progression in the context of the social construction of identity (Hamman, Gosselin, Romano, & Bunuan, 2010) integrating two theories: possible selves (Markus & Nurius, 1986) and figured worlds (Holland, Lachicotte, Skinner, & Cain, 1998). In the situation of a TEP, identity is defined as how PSTs perceive themselves as teachers (Lasky, 2005). To ultimately develop their professional identity, PSTs explore their various conceptions of possible selves (Ibarra, 1999). The possible selves are based upon their past experiences as K-12 students; their current TEP coursework experiences; and their field work and student teaching as well as their expected role as a teacher (Markus & Nurius, 1986). PSTs experiment with possible selves through approximations of practice (e.g., class presentations, one-on-one tutoring, and whole-class instruction) (Grossman, Compton, Igra, Shahan, & Williamson, 2009) and evaluate these experiences through self-reflection and feedback from others. Through repeated cycles, PSTs identify a set of possible selves, which will ultimately be integrated into their professional teacher identity (Ronfeldt & Grossman, 2008).

Challenges in PST identity development occur at various stages of a TEP. For example, the theoretical description of best practices offered by methods courses might not align with practices that PSTs observe in the field (e.g., Horn, Nolen, Ward, & Campbell, 2008; Smagorinsky, Cook, Moore, Jackson, & Fry, 2004). Challenges also exist early in a TEP, prior to field work. For instance, PSTs may struggle to play dual roles in TEP courses as they are both students in the course as well as developing teachers (e.g., Ma & Singer-Gabella, 2011). This struggle is an artifact of the PSTs dwelling within two figured worlds; that is, socially-constructed settings each possessing a distinct culture, value system, and purpose with regard to a teacher's role (Holland et al., 1998). Challenges stemming from navigating the various figured worlds are important opportunities for PSTs' growth towards their professional identity. However, without the support of a TE, such challenges can be overwhelming and potentially stifle the developmental process (e.g., Horn et al., 2008).

Successfully supporting PSTs in dealing with such struggle can lead to tensions in a TE's practice, especially as they are newly inducted into a TEP. In the field of teacher education, tension is described as the struggle TEs face as they are pulled in opposing directions when making pedagogical decisions (Berry, 2007). Berry outlines six tensions, three of which are relevant to the present study: *telling and growth*, *safety and challenge*, and *confidence and uncertainty*. *Telling and growth* is manifested in the struggles a TE faces between providing opportunities for the PSTs to build their personal knowledge through approximations of practice as opposed to the direct instruction often desired by the PSTs. *Safety and challenge* is revealed in the balance a TE must maintain in providing challenging learning experiences, while simultaneously ensuring that the PSTs feel sufficiently supported by the TE in order to accomplish the learning goals. *Confidence and uncertainty* emerges in how the TE must maintain the PSTs' confidence in his ability while also openly sharing his own uncertainty in dealing with unexpected situations that may arise during instruction. Recognizing and managing such tensions requires TEs to thoughtfully reflect upon their practice.

Methodology

Self-study is a methodology for examining one's practice in teaching about teaching (Loughran, 2005). The driving force behind self-study is the inconsistency that a TE experiences between what he intends for his classroom practices and what actually happens (Loughran & Northfield, 1998). There are no specific procedures that delineate self-study; however, it is characterized by certain qualities. Self-study uses data analysis to inform how to change one's practice; occurs in a real-time teaching setting; draws upon prior experiences, literature, and peer and PST consultation; ensures the validity and trustworthiness of the findings through rigorous qualitative inquiry methods; and shares the findings with the larger research community to add to the body of work examining best practices in teacher education (LaBoskey, 2004; Samaras, 2011).

Context and Participants

The present study examined my practice while teaching 24 PSTs (all female) who were enrolled in my class, Science for Elementary Teachers. This class was typically one of the first courses PSTs took in the College of Education (at a private university in the Southwest U.S.). The objective of the course was to guide the PSTs in learning to gather science content about specific natural phenomena via investigations of multiple sources (e.g., books, internet) in order to develop teacher knowledge for leading instruction with elementary students. Further, the PSTs experienced approximations of practice by sharing the results of their investigations with their peers. My intention was to use the iterative cycles of investigations and peer teaching to increasingly guide the PSTs in developing these skills. Conflict arose during one such investigation/teaching cycle, which focused on monarch butterfly migration, exposing contradictions between my perceptions and the PSTs' perceptions of my critical feedback.

Table 1
Data Sources and Descriptions

Data Source	Description
PST Coursework	During each investigation cycle, the PSTs worked in groups to prepare reports of the results of their investigations. These reports were useful in evaluating progress towards course objectives.
PST Journal Responses	PSTs completed two journal prompts provided by me in order to gain PSTs' perspectives on the conflict and my response to the conflict.
Class Discussions/Activities	In response to PST feedback, I purposefully designed several class activities and discussions to specifically address some of the underlying issues that contributed to the conflict.
Class Sessions	All class sessions were audio and video recorded, and a research assistant took field notes.
TE Journal	After reading the PSTs' responses to the first journaling assignment, I reflected upon the PSTs' perspectives as well as my own.
Peer Consultation	Throughout the self-study, I regularly relied upon peer consultation with my critical friend (second author), who was familiar with the TEP, the PSTs, and my pedagogical approach.

Data Sources and Analysis

To examine the underlying sources of the conflict and to modify my practice in response to what I learned, I drew upon data from a variety of sources. Typical of self-study research, much of the data resulted from classroom activities that I implemented as I adjusted my practice (Table 1).

Data were analyzed continually throughout the self-study, in consultation with my critical friend, using the constant comparative method (Glaser & Strauss, 1967). After we independently coded the initial journal responses, we discussed and refined the preliminary codes and ultimately organized them into three themes (*grades*, *components of a quality response*, and *need for guidance*). I used these three themes to guide my journal writing. We used the codes that were identified from the initial journal responses to analyze the second set, but recognized new codes that emerged. The new codes, which were revealed, informed the progression of the PSTs on two continua: *understanding instructor expectations* and *developing teacher identities*.

Results and Discussion

In response to the conflict, I initially assumed that the PSTs had not put sufficient effort into their monarch investigation as exemplified by the lack of content depth and misconceptions. However, the PSTs perceived my reaction as overly critical. Instead of moving on with the course schedule, I chose to identify the underlying sources of the conflict. In place of the next investigation, I assigned a journaling exercise with prompts such as: How did my reaction [to the monarch investigation] (and subsequent conversation) make you feel? The analysis of the PSTs' responses revealed the oversimplification of my initial interpretation of their work. Further, I learned about their conceptions about their role in the course and their understanding of the course objectives. Specifically, I learned about the PSTs' ideas regarding:

1. Grades – The PSTs were very concerned about earning high grades.
2. Components of a quality response – The PSTs did not know how to acquire, evaluate, and synthesize content knowledge for teaching; and instead equated quality for quantity.
3. Need for guidance – The PSTs believed that I had given insufficient guidance for them to successfully construct a quality response and felt that rubrics should be provided.

After reflecting on their journal responses, I recognized how the PSTs' perspectives differed from mine. I was focused on the PSTs' incremental growth through the iterative investigation cycles in conjunction with my feedback. I was confident that if they assimilated my feedback into their subsequent work (my guidance), their understanding of how to complete the investigations would develop (components of a quality response) and their performance would likewise improve (grades).

The contradiction between my intentions and how the PSTs were experiencing the course revealed that adjustments to my pedagogy were necessary to accomplish the course objectives. However, considering how to make such adjustments exposed tensions in my practice. How could I provide the PSTs more guidance, but still encourage their own construction of knowledge? How could I continue to challenge the PSTs to struggle while building a sense of security? How could I significantly alter my teaching practices while maintaining the PSTs' confidence in my leadership?

After considering these questions, I designed and implemented a series of activities to address the PSTs' misconceptions and concerns. For the first activity, I asked the PSTs to compose descriptions of a golden retriever and then led a group discussion analyzing the strengths and weaknesses of them. After the discussion, I presented a description of a Boston terrier and allowed the PSTs to critically analyze it and offer suggestions for improvement. Through this exercise, the PSTs learned what constitutes a comprehensive response to an investigation prompt as well as how to evaluate proposed responses. The second activity was created to address the PSTs' desire to have a rubric. I asked the PSTs to design a rubric for the monarch investigation. The PSTs realized that such a rubric would too directly lead the learner and thus negate the very purpose of the investigations. The third activity was a class discussion during which the PSTs conveyed what they believed to be the objectives of the course. The purpose of the activity was to demonstrate the intimate link between the course objectives and the investigation assignments. Following these three activities, I resumed the investigation cycle with the students investigating two additional phenomena and finally revisiting the investigation of monarch migration. The subsequent reports demonstrated marked improvement over the first monarch investigation.

To follow-up on the PSTs concerns and perspectives, I asked them to complete a final journaling exercise, which included questions such, as "How would you characterize a 'good answer' and "What have you learned from this experience?" The responses revealed growth by many PSTs and their progression along two continua (Table 2). The first continuum showed a range of understandings regarding course expectations. PSTs who *lacked an understanding* of the course expectations maintained misconceptions such as equating quality with quantity. Those PSTs with an *emerging understanding* recognized aspects of a quality response, yet continued to demonstrate misconceptions as well. PSTs who developed *full understanding* of course expectations recognized the importance of accessing and synthesizing content knowledge appropriate for teaching elementary science. The second continuum demonstrated a range of PST identities. Some PSTs persisted in *thinking like a student*, approaching the course solely from a student perspective (e.g., considering their personal interest as an important factor to engage in an assignment). Other PSTs, more advanced on this continuum,

Table 2

Continua of PST Growth Revealed from Analysis of Final Journal Reflections

Understanding Instructor Expectations	Developing Teacher Identities
Lack of Understanding I definitely appreciate the feedback on the assignment because it really helps me understand what I was missing and what you were expecting. Is it 'the more the better'? (PST 15)	Thinking Like a Student I do not know how much better I could have done on the Monarch investigation because it just wasn't interesting to me. (PST 4)
Emerging Understanding I know now that I should go beyond what is simply asked, and give a broader response to questions to show my knowledge. By doing so, I show the teacher that I researched and learned a lot about the topic. (PST 11)	Thinking about Teaching If I am teaching science in my classroom I need to make sure I am explaining things so that the kids can understand the information. … I need to work hard at knowing all I can about a topic so that I can explain it to my kids with ease. (PST 13)
Understanding …read as much as you can about the topic before you write down an answer so that you are writing from your own knowledge about the topic instead of just what it says on the website. For your answers try to think of things to answer (even if they aren't asked in the question) about what kids might ask questions about, this way you are elaborating on your answers. (PST 5)	Thinking Like a Teacher We went beyond just what the question asked and made sure to include information that would supplement the question as well as background information that would help the learner understand better. We also included more graphics to guide the learner along the way. (PST 1)

were *thinking about teaching*; that is, they were considering their future role as teacher, yet did not actually take on that persona. Finally, some PSTs began *thinking like a teacher*, taking on teacher identities, and intentionally constructing knowledge packets to maximize student learning.

By employing self-study to understand and deal with the conflict which occurred in my class, I was able to modify my practice to meet the PSTs' needs and repair the class culture through democracy and respect. The activities that I designed in response to the conflict assisted in accomplishing the course objectives and advanced the PSTs in developing their professional teacher identities as demonstrated by the PSTs' progression along these two critical continua.

Implications

Willingness to conduct self-study implicitly requires a TE to critically evaluate his practice. Instead of attributing the conflict to PST deficits, I chose to examine PSTs' perspectives and seek out how my teaching practices contributed to the issues that presented. Even though I ostensibly deviated from my initial course plan by engaging in self-study, the examination of my practice and subsequent modifications complemented my course objectives, illuminated my roles and responsibilities as a TE, and contributed to the PSTs' growth and development. Further, the self-study process repaired the class culture, reestablished trust, and modeled a pedagogy of reflection on one's practice. Several implications for TEs emerged from this research:

- PSTs do not automatically assume a teacher identity just because they are in a teacher education course,
- TEs should expect PSTs to fall along various points of the continuum of professional identity development, and
- TEs need to identify where PSTs are currently located on the continuum, understand their needs based on this location, and support them in progressing towards their professional identity.

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MEASURING MIDDLE SCHOOL STUDENT ATTITUDES TOWARD CLIMATE CHANGE

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A new fifteen-item climate change attitude survey was administered to 639 6th grade students as part of the evaluation for a project focusing on energy consumption. Factor analysis confirmed that the survey developed to measure middle school student attitudes toward the climate change assessed two constructs, one related to belief in global climate change and the other focused on intent to take actions to make a difference in the earth's environment. Students who participated in the project exhibited educationally meaningful increases in their beliefs that climate change exists and in their intentions to help make a difference in the global environment.

Introduction

While a large percentage (63%) of American adults report they believe in the existence of human influenced climate change, very few (14%) say they are "very worried" about it (Leiserowitz, Maibach, Roser-Renouf, Feinberg & Howe, 2013). Those surveyed see climate change as a distant threat that will impact future generations (Leiserowitz, et al., 2013). Americans were shown to be more skeptical than people in other countries (Carlsson, et al., 2010). Researchers have pointed to a lack of curriculum content regarding climate change in schools (Choi, Niyogi, Shepardson, & Charusombat, 2010) which could lead to students receiving more of their information from the media than teachers (Robertson & Barbosa, 2015). Adolescents' social and political attitudes are already strongly developed by the time they leave secondary school (Alwin & Krosnick, 1991; Sears & Funk, 1999). Therefore, the development of positive environmental attitudes in school-aged children is an important element in shaping behaviors in later life (Ballantyne, Connell, & Fien, 2006; Chawla, 1999; Meinhold & Malkus, 2005). Knafo and Galansky (2008) found a positive relationship between learning about the environment at school and the level of environmental concern. Researchers have concluded that educating students about the environment can influence their future behaviors (Sinatra, et al., 2012). This paper describes the pre-post changes in students' attitudes toward both beliefs and intentions regarding climate change issues resulting from learning about the ways in which the global climate is changing and probable causes for these changes.

Objectives of the Study

One goal of educating students about climate change and human impact on the environment is to create responsible adults who will make informed decisions regarding the environment in the future. This paper compares pre-post findings of treatment and comparison students related to climate change beliefs as well as the intentions to personally make changes to improve the environment. The research question that guided this data collection was whether treatment students who were studying standby power in their classroom became more positive in their beliefs and intentions regarding climate change than comparison group students.

Related Literature

Motivation to act on one's beliefs is an important step in enacting change (Sinatra, Kardash, Taasoobshirazi & Lombardi 2012). Findings suggest that students who have more favorable attitudes toward the idea of human-induced climate change are more likely to report a willingness to take action (Sinatra, et al., 2012). Other researchers have found that increasing environmental content knowledge in individuals results in more positive attitudes toward and responsible behavior toward the environment (Bradley, Waliczek, & Zajicek, 1999; McMillan, Wright & Beazley, 2004). As well, a connection between what is learned in science in school and environmental attitudes has been found (Karpiack & Baril, 2008). The 2006 Program for International Student Assessment (PISA) data also revealed a correlation between student performance in science and their environmental attitudes (Boeve-de-Pauw & Van Petegem, 2010).

Methodology

The Climate Change Attitude Survey (Christensen & Knezek, 2015) was completed by 639 middle school students in grade 6 participating in the Going Green! Middle Schoolers Out to Save the World (MSOSW) project. The middle school students were from 15 different U.S. treatment and comparison classrooms selected from seven states including California, Hawaii, Louisiana, Maine, Michigan, Virginia and Texas. While the teachers volunteered to participate in the project, there is not reason to believe the students are not representative samples from the schools they attend, which were themselves selected for their diversity in climate zones, rural vs. urban locations, socioeconomic status of their neighborhoods, and public versus private funding status.   These data, along with other attitudinal and content data related to STEM and demographic items, were gathered through an online server at the beginning (pre) and end (post) of the 2014-2015 school year as part of the project's data collection. The MSOSW project is funded by a U.S. National Science Foundation Innovative Experiences for Students and Teachers grant. In the MSOSW project, treatment classroom teachers attend an institute to learn about the energy-related curriculum and how to implement the curriculum with their students. MSOSW teachers are also provided with classroom sets of energy monitors, web enhanced teaching resources, curriculum and ongoing support from the project personnel. Comparison data were also gathered pre and post from students in 6^{th} grade who were not using the MSOSW curriculum. The focus of the curriculum and activities are related to standby power, which is power that is being used by appliances when they are plugged in but serving no useful function. The curriculum also includes estimating the impact that wasted power has on the changing climate in our world.

The 15-item survey contained Likert-type items on a 5-point scale from Strongly Disagree (1) to Strongly Agree (5) and was developed by the authors based on adaptations from other climate-related surveys intended for different audiences or different purposes (Champeau, 1997; Leiserowitz, et al., 2013). The 15-item survey included 5 items that were reverse coded. The instrument was found to be reliable and valid in initial trials with middle school students and factor analysis revealed two constructs (Christensen & Knezek, 2015). The current study's set of data revealed respectable reliability as measured by Cronbach's Alpha (.89 for Construct 1 and .78 for Construct 2). Construct 1 consisted on 9 items related to beliefs and included items such as "I believe there is evidence of global climate change". Construct 2 consisted of 5 items related to intentions and included items such as "We cannot do anything to stop global climate change" (reversed for coding).

Results and Discussion

Students who received the MSOSW curriculum treatment changed more in their attitudes toward climate change than the comparison group. As shown in Tables 1 and 2, students in both the treatment and comparison group showed statistically significant (p <.01) gains in Construct 1, the belief that there is evidence global change exists and has a negative impact, although for the treatment group the change was stronger. Regarding Construct 2, the students in the treatment group showed a significant gain (p<.01) regarding their ability to make a difference in the effects of climate change while the comparison group did not show significant gains. Effect sizes are also shown for each of the group changes on the two climate change constructs. The effect of the treatment (MSOSW activities) versus the comparison (normal school activities) on pre-post gains was ES = .51 for *Beliefs* and ES = .37 for *Intentions*.

Table 1

Treatment, 6th graders, pre-post

		N	Mean	Std. Dev.	Sig.	ES
Climate	pre	297	3.66	.64	< .0005	.89
Construct 1	post	245	4.20	.57		
Beliefs	Total	542	3.90	.66		
Climate	pre	297	3.46	.69	< .0005	.48
Construct 2	post	245	3.796	.74		
Intentions	Total	542	3.616	.73		

Table 2

Comparison, 6th graders, pre-post

		N	Mean	Std. Dev.	Sig.	ES
Climate	pre	342	3.60	.68	< .0005	.30
Construct 1	post	342	3.81	.70		
Beliefs	Total	684	3.70	.70		
Climate	pre	341	3.48	.71	.360	.07
Construct 2	post	342	3.53	.81		
Intentions	Total	683	3.50	.76		

As shown in Figure 1, the gains for the Going Green participants (treatment group) for both Construct 1: Climate Change Beliefs (ES = .51) and Construct 2: Climate Change Intentions (ES = .37) were sufficiently greater than gains for the comparison group students to be considered in the *Zone of Desired Effects* (Lenhard & Lenhard, 2015). Both surpass the effect size >= .3 criterion for the point at which the effect of an intervention is considered educationally meaningful (Bialo & Sivin-Kachala, 1996). These findings are graphically displayed in Figures 2 and 3.

Individual item analysis was conducted for the climate change statements in the survey. Thirteen of the 15 items were significantly ($p<.05$) higher at post test time than pretest time for the treatment students while 8 of the 15 items were significantly higher ($p<.05$) from pretest to post test for the comparison group. The three items for which the treatment students gained significantly ($p < .01$) pre-post but the comparison students did not, are shown in Table 3.

d	r*	η^2	Interpretation sensu Cohen (1988)	Interpretation sensu Hattie (2007)
< 0	< 0	-	Adverse Effect	
0.0	.00	.000	No Effect	Developmental effects
0.1	.05	.003		
0.2	.10	.010	Small Effect	Teacher effects
0.3	.15	.022		
0.4	.2	.039		Zone of desired effects
0.5	.24	.060	Intermediate Effect	
0.6	.29	.083		
0.7	.33	.110		
0.8	.37	.140	Large Effect	
0.9	.41	.168		
≥ 1.0	.45	.200		

Figure 1. *Guidelines for interpretation of effect size magnitudes.* (Lenhard & Lenhard, 2015)

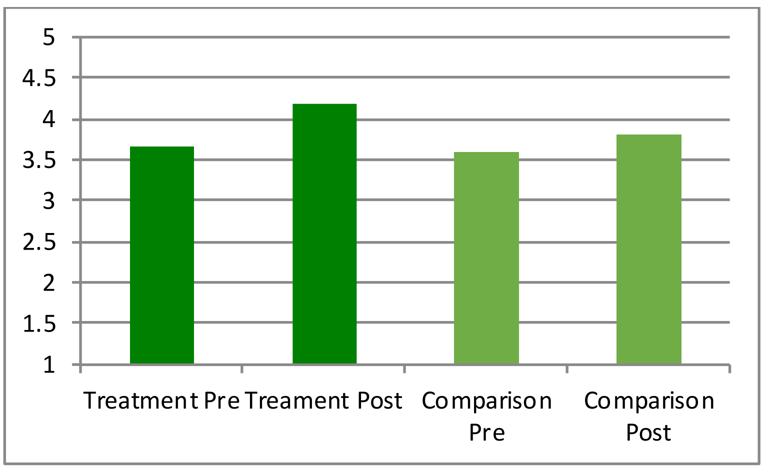

Figure 2. *Pre-post gains for treatment versus comparison group for Going Green! MSOSW sixth grade students on construct 1: climate change beliefs*.

Findings Regarding Gender

When comparing data by gender, large differences were confirmed for the treatment males students versus the comparison male students. Both of the constructs on the survey changed significantly pre to post for treatment males but not for comparison males:

- The effect size between Treatment males and comparison males for Construct 1 is .58 and Construct 2 is .42
- Effect size between Treatment females and comparison females for Construct 1 is .40 and Construct 2 is .31

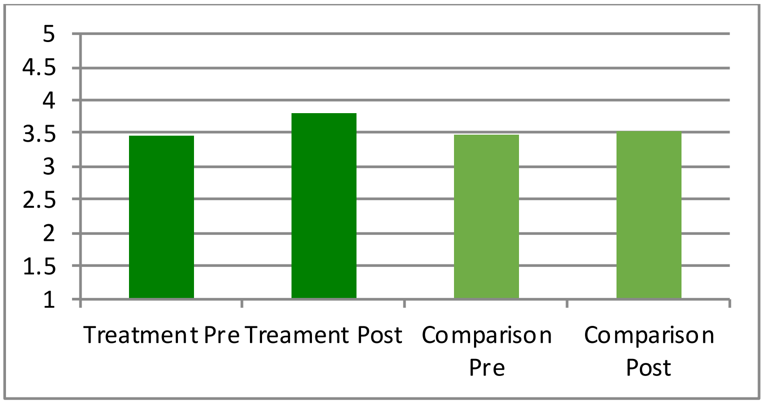

Figure 3. *Pre-post gains for treatment versus comparison group for Going Green! MSOSW sixth grade students on construct 2: climate change intentions.*

Table 3
Comparison of Individual Climate Change Items with Significant Changes in Treatment Students

Group	Item	Time	Mean (SD) n	Sig.
Treatment	I can do my part to make the world a better place for future generations.	Pre	3.99 (.90) n = 293	.000
		Post	4.29 (.73) n = 242	
Comparison		Pre	3.95 (.91) n = 336	.352
		Post	4.02 (.99) n = 340	
Treatment	Things I do have no effect on the quality of the environment (Reversed for coding)	Pre	3.33 (1.05) n = 296	.000
		Post	3.70 (1.02) n = 244	
Comparison		Pre	3.35 (1.06) n = 338	.637
		Post	3.39 (1.10) n = 340	
Treatment	It is a waste of time to work to solve environmental problems. (Reversed for coding)	Pre	3.99 (1.07) n = 295	.008
		Post	4.22 (.90) n = 244	
Comparison		Pre	4.03 (.98) n = 339	.684
		Post	3.99 (1.10) n = 340	

Table 4
Comparison of Treatment and Comparison Male Students on Climate Change Constructs

Construct	Group	Pre	Post	Sig.	ES
Construct 1 Beliefs	Treatment	3.67 (.69) n =147	4.19 (.57) n = 120	.000	.81
	Comparison	3.68 (.66) n = 186	3.80 (.76) n = 185	.121	.17
Construct 2 Intentions	Treatment	3.34 (.73) n = 147	3.71 (.73) n = 120	.000	.50
	Comparison	3.44 (.70) n = 186	3.58 (.87) n = 185	.634	.05

Table 5

Comparison of Treatment and Comparison Female Students on Climate Change Constructs

Construct	Group	Pre	Post	Sig.	ES
Construct 1 Beliefs	Treatment	3.65 (.58) n = 150	4.20 (.58) n = 125	.000	.95
	Comparison	3.50 (.69) n = 156	3.82 (.61) n = 157	.000	.49
Construct 2	Treatment	3.57 (.63) n = 150	3.88 (.72) n = 125	.000	.46
Intentions	Comparison	3.52 (.73) n = 155	3.59 (.73) n = 157	.400	.10

Discussion of Implications

Note that as reported in Tables 1 and 2, the gains in Climate Change Beliefs pre to post for the comparison group, as well as for the treatment group, were sufficiently large to be rare by chance (p < .0005), implying that some other influences such as severe weather reported across the US in 2014-2015 may have also contributed to student change in climate change beliefs during the course of the school year. Nevertheless, much greater gains resulted across classrooms participating in the Going Green project. This provides strong evidence that Going Green activities were effective in fostering more positive climate change beliefs as well as intentions to take action. Teaching students about the impact they have individually and collectively on the environment through hands-on, real world curriculum can foster global citizens who intend to participate in taking action to improve the earth's environment.

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TEACHING FOR CONCEPTUAL UNDERSTANDING: WHAT PRECALCULUS TEACHERS HAVE TO SAY

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Quantitative analysis of the Factors Influencing College Success in Mathematics (FICSMath) Survey data indicates that high school mathematics teachers' abilities to teach for conceptual understanding is a significant and positive predictor of student performance in single-variable college calculus. To explore these findings more in depth, we gathered and analyzed interview data gained from a representative sample of high school precalculus teachers identified as requiring high levels of conceptual understanding on the FICSMath Survey. Preliminary analysis of this data suggests that the development of mathematical language, literacy, and thinking are critical to these efforts.

Introduction

The Factors Influencing College Success in Mathematics (FICSMath) Project is the first national study on the secondary preparation for single variable college calculus success. The FICSMath study was designed after researchers involved in the Factors Influencing College Success in Science (FICSS) Study found secondary mathematics to be the only significant and positive predictor of performance across college biology, chemistry, and physics at the freshman level (Sadler and Tai, 2007).

In the fall of 2009, 10,492 students enrolled in their first college/university single variable calculus course across the U.S. completed the FICSMath Survey. The survey consisted of 70 items that collected student data around three domains. The second section (and the majority of survey items) is the most relevant to this study as it asked students to share their perceptions about the 'most advanced' high school mathematics course they took in relation to a) organization and structure; b) textbook, homework, and in-class assignments; c) tests and quizzes; d) the teacher; and class time and methods. Students had the option of providing their mathematics teacher's name and the high school they attended. Professors held the completed surveys until the end of the semester so that students' final grades in college calculus could be reported. As a result, the relationships between student perceptions of their prior learning experiences and their actual performance in college calculus could be ascertained.

Related Literature

Analysis of the FICSMath Survey data revealed that high school mathematics teachers' abilities to teach for conceptual understanding is a significant and positive predictor of student performance in single variable college calculus (Wade, 2011). Although national standards identify what students are to learn (NGA, 2012; NCTM, 2000), how teachers support students' understanding of challenging precalculus concepts and applications remains relatively unknown. The dearth of research on this topic has led to the Mathematical Sciences Education Board's call for formal studies of the relationship between the pedagogy of high school mathematics teachers and student preparation for university level mathematics (Harwell et al., 2009; Bressoud, 2009).

Understanding what teachers do to promote conceptual understanding and prepare students for future success in college calculus holds considerable value. Mathematics professors and secondary mathematics teachers agree that rigorous instruction promotes mathematical understanding, but there is less agreement on how to implement such instruction (Harwell et al., 2009).

Objectives of the Study

The purpose of this study was to qualitatively explore quantitative results discovered in the first phase of the FICSMath Project. This first phase indicates that a high school mathematics teachers' abilities to teach for conceptual understanding is a significant and positive predictor of student future performance in single variable college calculus (Wade, 2011). Accordingly, we explore what teachers do to promote high conceptual understanding and prepare students for future learning or what some call transfer (Van Merriënboer, Kester, Paas, 2006) in college calculus.

For the second (and qualitative) phase of our study, we conducted semi-structured, open-ended interviews with a representative sample of high school precalculus teachers (N=11) whose students identified them on the FICSMath Survey as requiring high levels of conceptual understanding. Our goal was to understand what these teachers identify as important to promoting a high level of conceptual understanding and preparing students for future success in college level calculus. The following research questions framed the second phase of our study:

1. How do these teachers define conceptual understanding in mathematics?
2. How do they help students gain that understanding in their courses?

3. What do these teachers identify as important to student success in college-level calculus?
4. How do they prepare their high school students for success in college-level calculus in their courses?

Methodology

This research follows a *sequential explanatory mixed methods design* (Creswell, 2012) in that it involves in-depth qualitative exploration of quantitative results discovered in the first phase of the FICSMath Project. When used in combination, qualitative and quantitative methods complement each other and “provide a more complete picture of the research problem” (Ivankova & Stick, 2007).

The objective of all qualitative research is to develop an “in-depth understanding of a central phenomenon” drawing on the information that the study participants provide (Creswell, 2012, p. 206). Use of an open-ended interview protocol allowed us to dig deeper into the findings gained from statistical testing, and explore teaching for conceptual understanding and transfer using these teachers’ words and perspectives. While we recognize the limited nature of self-reported data gained through interviews, we believe interviews provide access to useful information especially when participants are geographically dispersed (as they were in this study) and direct observation is not possible (Creswell, 2012).

Participants

Of the 10,492 students who completed the FICSMath survey, a subset of 2,326 students had precalculus their senior year in high school. Within this subset, 1,285 reported that their secondary senior level precalculus teacher required high conceptual understanding. To gain a representative sample by geographical region, teachers from each of the U.S. Census Regions were contacted (24 from the West, 21 from the Midwest, 17 from the South, and 17 from the NorthEast). Of the 79 teachers contacted, eleven (6 females; 5 males) agreed to be interviewed. Table 1 reflects that distribution and the number of years each participant had been teaching mathematics, including but not limited to precalculus.

Analysis

A “mixed strategies” approach to cross-case analysis was used to analyze interview data so that themes across cases could be identified (Huberman & Miles, 1994). At the time of this paper submission, two additional interviews with male participants are needed to complete the study. As a result, we tentatively share preliminary findings based on categories of comments found in analysis of all of the interview data collected and analyzed thus far.

Table 1.
Distribution and Number of Years of Experience of Participants

Region	West	Midwest	South	Northeast
Teachers Interviewed	Female 16 years experience	Female 41 years experience	Female 32 years experience	Female 24 years experience
	Male 22 years experience	Male 9 years experience	Male 15 years experience	
	Male 9 years experience	Male 27 years experience	Female 29 years experience	
		Male 20 years experience		

Results and Discussion

Preliminary analysis of interview data suggests that these teachers deemed the development of mathematical language, literacy, and thinking as critical to the teaching for conceptual understanding and preparing students for future success in single-variable college calculus. While these teachers wanted students to “pass state and district testing,…that’s not what’s important in the big scheme of things.” (KfT1). What was important was helping students see the value of mathematics in the world and their own lives, learn how to learn, and apply what they learn to overcome challenges and strive towards meaningful goals.

Mathematical Language

All of the teachers consistently reported that they saw the learning of mathematical language as foundational to both student success and conceptual understanding. As one teacher confirmed: It is important “that they understand the concepts, symbols, what they mean, and the properties of various functions because all of that leads to further understanding” (WfA1). By helping student acquire the language of mathematics [and precalculus]—to the point of automaticity and what some call fluency—students could then dig deeper into mathematical content and processes. This finding is not to be taken lightly. As Kenney (2005) points out, “Mathematics is truly a foreign language for most students” thus making its acquisition “an extremely difficult process” (p. 3). Reasons for this phenomena are many with the greatest difficulty stemming from the "double decoding" that occurs during the entire process:

> Double decoding…occurs when we first encounter written mathematics or symbols, which must first be decoded, and then connected to a concept that may or may not be present in prior knowledge even in an elementary way" (p. 5)

Wakefield (2000) suggests that mathematical language requires memorization of symbols, algorithms, and abstractions that improves over time with practice. Furthermore, Wakefield posits that the meaning of mathematical language is influenced by symbol order (or syntax) and that understanding requires both decoding and encoding. In sum, these teachers provided explicit instruction around mathematical language so that students gained mathematical fluency that supported their understanding of mathematical concepts at a deeper level.

Mathematical Literacy

A second theme centers on teacher efforts to provide multiple and varied opportunities for students to understand and express their understanding of mathematical content and processes using text (broadly defined as spoken, written, visual, and symbolic representation). These teachers shared content-specific strategies that they used to engage students in reading, writing, listening, speaking, viewing, and presenting concomitant with the learning of precalculus. Rather than seeing literacy and the learning of mathematics as an either/or proposition, these teachers embraced the genius of "and" by seamlessly integrating *disciplinary literacy* or *the "nuanced examination of the literacy practices valued by the discipline*" and the learning of precalculus (Pytash and Ciecierski, 2015, p. 15). In so doing, they did what is crucial to helping adolescents "approximate what insiders do as readers and writers [and thinkers] in their discipline" (Buehl, 2011, p. 268). Interestingly, disciplinary literacy is an area that remains the most neglected at the secondary level (McCombs et al. 2005). Furthermore, mention of the word *literacy* is implied but not explicitly stated in the *Common Core State Standards for Mathematics* (NGA 2010).

Teachers also mentioned seeking to promote conceptual understanding by explaining or showing mathematical content or problem solving in more than one way. While not specifically referenced by name, much of what these teachers do aligns with the *Rule of Four* and the use of geometric/graphic, numeric, analytic/algebraic, and verbal representations to understand and demonstrate what it means to be literate in mathematics. Ideas important to Universal Design for Learning are also worth noting, especially in terms of providing students with multiple means of representation (Principle 1) and multiple means of action and expression (Principle 2). For more information, see: http://www.udlcenter.org.

Mathematical Thinking

A third group of responses focused on developing students' understanding of mathematics as the science of patterns and the aggregate of mathematical knowledge, skills, abilities, habits and attitudes embodied in the Common Core's Standards for Mathematical Practices [NGA, 2010]). According to Devlin (2011), the idea of reducing abstract ideas (and processes) to their bare essentials is vital to mathematical thinking:

> *Mathematical thinking* is more than being able to do arithmetic or solve algebra problems….Mathematical thinking is a whole way of looking at things, of stripping them down to their numerical, structural, or logical essentials, and of analyzing the underlying patterns. (p. 59)

To help students gain conceptual understanding, one teacher asked students to "demonstrate a firm grasp of the essential…[by having them explain] the meaning behind the meaning in as few words as possible" (BfM1). For example, "A vector is a distance with a direction" or "A logarithm is an exponent." Another shared similarly: " I teach in a way that they [students] remember the general concept and not the minutiae" (EfW1). Likewise, all teachers identified the importance of helping students see how everything "fits" or relates and in turn, asking students to put this understanding to use in challenging, meaningful, and novel ways. All of the teacher responses align with the call to focus less on computational skills and learning procedures to solve problems, and focus more on helping students 'learn how to learn' and develop "a good conceptual understanding of mathematics, its power, its scope, when and how it can be applied, and its limitations" (Devlin, 2011, p. 21). What is clear, these teachers' efforts align with developing mathematical thinking that leads to their students' future success in college calculus.

Implications

Traditional cognitive perspectives describe learning as an individual's acquisition of knowledge, change in knowledge structures, or growth in conceptual understanding (Borko et al., 2000). Skemp (2006) suggests that two different types of conceptual understandings develop in school mathematics: relational and instrumental understanding. Relational understanding implies that students know what to do and why, while instrumental understanding indicates that students know rules without reason. Secondary teachers often adopt a two-track strategy of instruction where they spend some time on drill and practice, providing for skills and facts, and some time on relational understandings (Skemp, 2006). The administrative demands for standardized tests to provide “unambiguous documentation of learning” are likely to add to the drill and practice instructional experiences (Pesek & Kirshner, 2000, p. 524). As a consequence, pedagogies that support students’ relational understanding in secondary mathematics, and suggested by this study, may be undervalued. If students fail to grasp mathematical concepts, or if they grasp concepts but cannot connect them to relevant procedures, then students generate flawed procedures that result in systematic patterns of errors (Siegler, 2003). What this study suggests is that the development of mathematical language, literacy, and thinking promotes conceptual understanding in precalculus and prepares students for future success in college calculus. Much depends, therefore, on the robustness of the instruction that mathematics teachers provide at the high school level (Clark & Lovric, 2009).

These findings corroborate quantitative findings discovered in the first phase of the FICSMath Study.

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ADVANCING SCIENTIFIC LITERACY WITH INQUIRY LESSON PLANS USING SCIENCE READING MATERIALS

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Science teachers at all grade levels are being asked to incorporate more literacy strategies into their lessons to support literacy in language arts. Teachers can advance scientific literacy through reading and writing about science in the classroom using engaging articles that examine the science behind everyday life. Lesson plans were designed using the backward design process, by first examining the standards to identify learning goals. The goal of these lessons is to help students think critically as they use interesting reading content to deepen their scientific understanding of how we know what we know.

Introduction

The major goal of science education should be to advance science literacy for all students so they can participate fully as thoughtful citizens in our global society (Rutherford & Ahlgren, 1990). Science can inform everyday decisions related to personal and societal health, the environment, and hazards, whether natural or human-made. Therefore, it is critical to teach students how to evaluate scientific claims when they read (or hear) scientific information. This paper will describe how guided inquiry lesson plans based on engaging scientific articles were designed using the backward design process (Wiggins & McTighe, 1998), by first examining the standards to identify learning goals. The goal of these lessons is to help students think critically as they use interesting reading content to deepen their scientific understanding of how we know what we know. Students apply the literacy skills of reading, writing, and listening during meaningful classroom lessons using engaging nonfiction, including articles found in journals, newspapers, and magazines. Through reflective writing, students can relate their learning to their lives.

Purpose of the Paper

The purpose of this paper is to describe the process used to create inquiry-based lesson plans that promote conceptual understanding of important scientific topics. The lessons include opportunities for students to develop language arts skills including reading, writing, speaking, listening, and viewing. The lessons help students understand scientific processes, evaluate scientific claims when they read, and relate their learning to their lives, thus minimizing memorization of scientific concepts. The lessons develop critical thinking skills, deepen understanding of the nature of science, and increase student motivation to learn scientific concepts.

Instructional Framework and Related Literature

To develop deep scientific understanding, students should examine how we know what we know. Some textbooks focus only on what we know, and critical thinking is overlooked in a push to “cover” scientific content. In science, students often read text uncritically, readily accepting claims made by the author even when they disagree with the author (Phillips & Norris, 1999). Other students believe science is a collection of facts they can choose to believe or not. These preconceptions do not advance student learning, so teachers should know how to address reading comprehension and naïve conceptions in science.

For enduring knowledge and understanding, the teacher must facilitate and direct learning through questioning and posing problems, enabling students to reorganize their mental structures**.** Thier (2002, p. 100) advocates that teachers in both inquiry-based and textbook-based classrooms should model reciprocal teaching strategies for students, including pre-reading, active reading, and post-reading activities. Teachers must activate students’ prior knowledge, establish a purpose for reading, and encourage student reflection on how their understanding changes as they synthesize new information from reading (Strong, Perini, Silver, & Tuculescu, 2002).

Thier (2002, pp. 7-8) compared skills of a scientist with literacy skills, and found many similarities, including noting details, comparing and contrasting, predicting, sequencing events, distinguishing fact from opinion, and making inferences. These commonalities support the integration of student inquiry with reading in the science classroom because neither reading nor inquiry alone is sufficient to learn science. The *National Science Education Standards* (National Research Council, 1996) state “Conducting hands-on science activities does not guarantee inquiry, nor is reading about science incompatible with inquiry” (p. 23). Pratt and Pratt (2004) caution that while the object of learning in science is understanding physical phenomena in the natural world, the object of reading comprehension is understanding content described in the text. They state, “The challenge of classrooms today is to bring the supportive skills from literacy and inquiry science together in a truly integrated way to support the goal of learning science content” (p. 397).

Reading science requires knowledge of some unique text features and strategies that may be different from other subjects, such as how to interpret tables and graphs. Students should read "real" books and articles, not just the textbook, and students should be taught thinking skills that effective readers use (Daniels & Zemelman, 2004). Glynn and Muth (1994, p. 1062) suggest that science students read a variety of text to gain reading fluency, including newspaper stories, trade books, biographies of scientists, and even science fiction. Reading should be active, and engaged readers are far from bored.

Students today can easily find scientific information on the Internet, but they need to develop skills to evaluate the validity of the information. Students' ability to learn on their own can be greatly enhanced by integrating reading, writing, and science to help them make connections. The teacher's role in teaching explicit reading and writing skills to students who are actively engaged in studying natural phenomena is critical (Alvermann & Moore, 1996; Loring, 1997). Research suggests that as science teachers teach, they should explicitly model appropriate reading processes and strategies to improve student understanding of scientific concepts as well as methods of inquiry (Baker, 2004). Explicit instruction, modeling, explaining, demonstrating, and even reading aloud while describing thinking processes will support students as they acquire complex literacy strategies (Allington, 1994; Loring, 1997). For enduring knowledge and understanding, the teacher must facilitate and direct learning through questioning and posing problems, enabling students to reorganize their mental structures, recognize and give up their incorrect strategies, and find new ones (Lawson, 1994).

Students have a natural curiosity about science, and many enjoy reading scientific books and articles of interest to them (Daniels & Zemelman, 2004; Thier, 2002). Science teachers can capitalize on this interest by encouraging and promoting student reading and writing related to the science content in their course. When developing the lesson plans using the process described in this article, the teacher should be sure to place emphasis on searching for evidence to support scientific claims as students inquire into how we know what we know in science. This is enhanced when students read a variety of science texts from the Internet, science magazines and trade books to supplement their textbooks. Studying the history of science may help students discover their conceptual weaknesses because often they will find their own alternative conceptions were held by earlier people, including scientists (Wandersee, Mintzes & Novak, 1994).

Practice or Innovation

The integrated science and literacy lessons are planned using the backward design process (Wiggins & McTighe, 1998), beginning with student learning goals in mind to support deep understanding. First, select the relevant standards for science content and processes, as well as reading and writing. The standards describe what students should know, understand, or be able to do after the lesson. If using the *Next Generation Science Standards* (NGSS Lead States, 2013), the science learning goals are derived from the disciplinary core ideas, crosscutting concepts, and science and engineering practices (SEPs). Six of the eight SEPs explicitly include reading and/or writing:

- Asking questions (for science) and defining problems (for engineering)
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations (for science) and designing solutions (for engineering)
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

Related Common Core English Language Arts Standards for reading and writing may be found in Appendix M of the *Next Generation Science Standards* (2013), or teachers may use their state standards for science and English language arts.

In today's world, there are many resources available to provide opportunities for students to construct science understanding through reading and writing. The reading materials chosen should be of high quality, scientifically accurate and interesting to students from diverse backgrounds. Articles, whether print or web-based, should include specific reference to where the information came from or how it was obtained so that students can learn how to distinguish scientific knowledge from opinion. The text and pictures should be appropriate for the targeted grade level. The article should reinforce scientific vocabulary, but learning new vocabulary should not be the focus of the article. Look for articles that help students connect new information to their existing knowledge.

Next, write learning goals, including guiding questions and objectives. Well-planned guiding questions to promote conceptual understanding are a critical component of the lesson plans. They should be provocative or stimulating, relating to students' lives. Write at least three student learning goals or objectives based on the standards, one each for science, reading, and writing. Consider what possible naïve conceptions or preconceptions students might have about the topic.

With the science learning goals in mind, consider how students will demonstrate their understanding at the end of the lesson or unit. Conceptual understanding can be demonstrated in a variety of different ways. For example, students can apply and use the new information in a different context, build a model, or create a presentation for an audience outside the classroom. The final assessment could also be as simple as a paragraph or letter, or as elaborate as a project or role play (including debate). Writing for an audience other than the teacher makes the assessment more relevant to the students' lives, and therefore more interesting and motivating for them. It is very helpful to create the rubric for the final assessment before planning the lesson itself.

Begin planning the activity part of the lesson using a guided inquiry model such as the conceptual change model (Posner, Strike, Hewson & Gertzog, 1982) or the 5E (Engage-Explore-Explain-Elaborate-Evaluate) model (Bybee, 2014). To promote conceptual change, students' prior knowledge must be explicitly addressed, so they can confront the difference between their ideas and the text. Activate students' prior knowledge by asking them to individually make a prediction, answer an engaging question, or complete an anticipation guide. Formative assessment probes such as those developed by Keeley, Eberle, & Farrin (2005) are also very useful. Use simple language in a non-threatening environment. When students are finished, ask them to share their ideas with their group or students sitting nearby (think-pair-share). Invite students to communicate what they discussed in their groups before providing the reading strategy you have chosen. This discussion will allow the teacher to know what the students already know so that good questions can be developed to scaffold student understanding.

The reading strategy should fit the learning goals of the lesson and lead to the final assessment. As students read, they should link concepts with evidence to support their new understanding. Possible reading strategies for a final assessment that is a letter or presentation include two-column notes, distinguishing fact from opinion, or making inferences. If the final assessment is a debate, a Venn diagram or T chart is a good reading strategy to choose. Flowcharts are appropriate if students create a model or project for the final assessment. The Science Writing Heuristic, Part II (Hand & Keys, 1999), was developed to help students report inquiry investigations in a laboratory, but it can be applied to reading contemporary scientific reports as well as historical accounts of scientific investigations. The steps are:

- Beginning Ideas: What was being investigated? What was the hypothesis or prediction?
- Tests: What did the researcher(s) do?

- Observations: What happened?
- Claims: What did the researcher(s) claim?
- Evidence: How did the observations support the claims?
- Reflection: How have your ideas changed? What did you learn? What do you still wonder about?

Teachers may also create their own graphic organizers to help guide students as they read. Students should record the information in their own words as they read and re-read the article. The goal is for students to explain the new information in their own words and demonstrate conceptual understanding, so avoid questions that have answers that can be found directly in the text. If students are fluent readers, they may choose their own reading strategy.

After reading, classroom discussions with well-planned guiding questions are crucial to promote conceptual change. Students can compare their understanding with their classmates and share insights they have gained from their reading. A safe, relevant science activity, demonstration, or video clip may help students confirm their new ideas. As students learn to inquire by reading independently, they should be encouraged to search for evidence to support new scientific learning. Students may think of their own scientific experiments or investigations to confirm their understanding, but the teacher must ensure activities designed by students are safe. To finish the lesson, students complete the final assessment and reflect on their new understanding.

Classroom Examples

Both preservice and practicing teachers have created and used lesson plans for a variety of grade levels using the ideas presented in this paper. Their students come from diverse backgrounds and many have special needs. Some of the lesson plans such as "Florida Panthers and Wildlife Corridors" (Resource ID 50971) have been published in CPALMS (www.cpalms.org), Florida's online resource center with high-quality instructional materials aligned to Florida's standards. If teachers do not have time to create their own lesson plans, they can use the ideas in this paper to make sure the standards, learning outcomes, assessments, and activities are aligned. Teachers can share their lessons with others in their schools and districts, or online sharing platforms such as Google docs or Basecamp, as well as at state and national conferences.

As they learn to use the backward design process, teachers report having to make a cognitive shift to start with the end in mind basing the lessons on the standards, writing learning goals, and developing the final assessment before jumping to the activity part of the lesson plan. However, once they have done this they find that linking the “hook” in the engagement part of the lesson to the end product is greatly facilitated. The entire lesson is then better aligned to ensure greater student understanding. When teachers use these lessons with their students, they report greater student engagement and interest. Further, students develop a deeper understanding of how science impacts their lives so they can make thoughtful decisions as citizens in our democratic society.

Implications

Integrating science and literacy can greatly enhance scientific understanding, but it is important to remember that reading alone is insufficient for conceptual change to occur. Teachers should include relevant science laboratory activities, demonstrations, simulations, and other active learning strategies in their instruction. Supporting claims with evidence is critical when reading as well as during hands-on activities. Additional implementation is needed to demonstrate the value of integrating language arts skills with science in engaging lessons to help students develop deep understanding of important scientific concepts. More research is needed to substantiate the effectiveness of this approach on K-12 learning outcomes.

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NASA PRESERVICE TEACHER INSTITUTE: COMPARING FOUR MODELS FOR INDICATORS OF EFFECTIVE PRESERVICE SCIENCE TEACHER TRAINING

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NASA's Preservice Teacher Institutes (PSTI) provided content-based training for preservice teachers (PST) at NASA centers. The purpose of this mixed-methods study was to analyze the effectiveness of four PSTI models conducted at two NASA centers. Results suggested that face-to-face workshops that provided PST with an opportunity to teach lessons to students positively influenced participants' science teaching self-efficacy. Additionally, the sequencing of components of the hybrid PSTI models may have affected learning and attitude outcomes. Findings of this study suggest that PST may benefit more in a face-to-face learning environment, especially in a science content area.

Introduction

NASA's PSTI seeks to increase the number and diversity of elementary PST who enter the teaching profession equipped with the teaching self-efficacy and content knowledge to increase their students' cognitive achievement in STEM areas and improve students' attitudes toward STEM and STEM careers. To achieve this goal, PSTI provided elementary PST with content-based training through experiential learning activities at NASA centers. PSTI has traditionally been delivered through one-week or two-week in-person training workshops. Increased budgetary constraints within the federal government have resulted in a trend to embrace online educator training programs as a method to expand participation and lower the cost per participant. However, in the push to move toward more cost effective delivery mechanisms, few studies have compared the effectiveness of online professional development to face-to-face experiences or hybrid experiences that include both face-to-face and online components (Means, Toyama, Murphy, Bakia, & Jones, 2010).

Objectives of the Study

The purpose of this study was to analyze the effectiveness of four PSTI models representing a variety of delivery methods conducted at two NASA Centers between 2013-2014. Two research questions guided this study: (a) How do the four PSTI models differ? and (b) How does participation in each PSTI model affect participants' science teaching self-efficacy, outcome expectancy, and attitudes towards science teaching and learning?

Theoretical Framework

Mohr-Schroeder, M. J., & Thomas, J. N. (Eds.). (2015). *Proceedings of the 114th annual convention of the School Science and Mathematics Association.* Oklahoma City, OK: SSMA.

The *2012 National Survey of Science and Mathematics Education* provided evidence of the national need to better prepare elementary educators to teach science (Banilower et al., 2013). The study found elementary teachers perceived themselves as less prepared to teach science than other subjects and felt least prepared to teach physical science and engineering. When viewed through the lens of Social Cognitive Theory (SCT; Bandura, 1977), these elementary school teachers may be less likely to allocate instructional time to teaching science and to persist to overcome challenges while teaching science. According to SCT, individuals are less likely to perform actions they do not believe they have the ability to perform (personal teaching efficacy) and that will not have favorable outcomes (outcome expectancy) (Bandura, 1977).

Methodology

Context

The four models selected for this study represented a variety of lengths and delivery mechanisms (Figure 1). All four models focused on NASA content; provided PST access to current NASA missions and science research, facilities, and education resources; and included an in-person experience held at a NASA Center. The in-person experiences included presentations on science content and pedagogy, hands-on activities, lesson planning, and research facility tours.

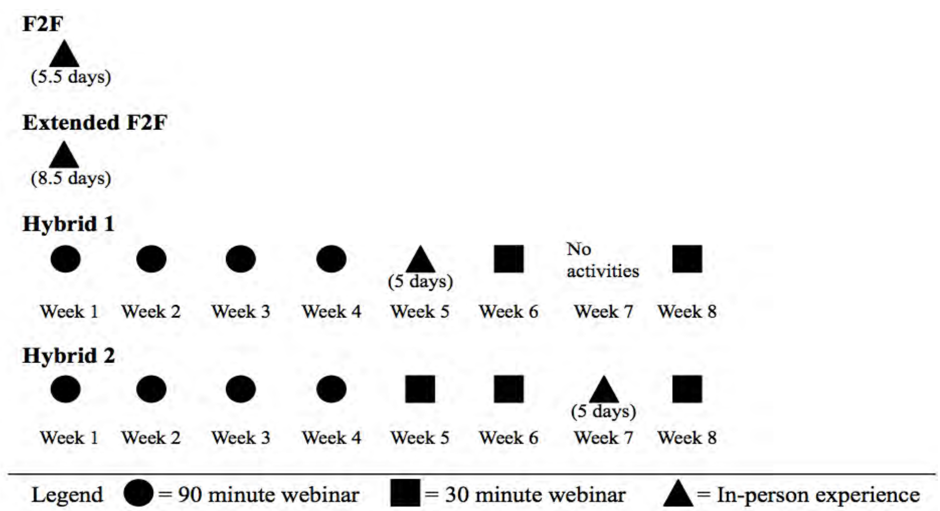

Figure 1. Summary of the four PSTI models.

Two of the models were conducted completely in-person: Face-to-Face (F2F) and Extended F2F. These models included similar science and pedagogical content; however, they were held at different NASA Centers and varied in length. Both F2F and Extended F2F included a teaching experience during which PST prepared lessons plans and then instructed the lessons to elementary students. The remaining two models were hybrid designs that included an in-person component and additional training opportunities delivered through online learning experiences prior to and after the in-person experience. The hybrid models were held at the same NASA center and included similar science and pedagogical content; however, they varied in the sequencing of the online and in-person components.

Participants

Participants in all models were undergraduate students pursuing education degrees and teacher certification. To recruit participants, informational flyers were e-mailed to education faculty at minority serving institutions. Information was also posted to NASA social media and disseminated through NASA education distribution lists. PST applied to participate in PSTI through an online application and were selected through a competitive process. Selection criteria included coursework completed, GPA, and a short essay explaining why they wanted to participate in PSTI. Selection preference was given to students attending minority serving institutions. Table 1 lists participants' demographic information.

Table 1.
PSTI participant demographics

	Participants n (%)							
Demographics	F2F		Extended F2F		Hybrid 1		Hybrid 2	
Participants								
Total number of participants	65		19		25		25	
Number of study participants	63	(97)	19	(100)	18	(72)	13	(52)
Academic Status								
Number of seniors	63	(100)	12	(63)	18	(100)	13	(100)
Number of juniors	0	(0)	7	(37)	0	(0)	0	(0)
Mean GPA	3.78		3.49		3.57		3.50	

Research Design

A fixed, concurrent mixed-methods approach was used to collect and analyze qualitative and quantitative data simultaneously. Researchers mixed qualitative and quantitative data during interpretation.

Qualitative Analysis

Content analysis of PSTI agendas looked for evidence of effective professional development: (a) Focusing on content, (b) Promoting active learning, and (c) Fostering coherence (Garet et al., 2001). Participants' responses to open-ended survey questions were analyzed using open and focused coding processes described by Creswell (2007). The open-ended questions were: (a) Would you recommend PSTI to another preservice teacher? What would you say? (b) In your own words, how has this workshop affected your understanding of teaching STEM with NASA resources? and (c) Other comments or suggestions for PSTI.

Quantitative Analysis

The Science Teaching Efficacy Beliefs Instrument for PST (STEBI-B) was used to assess participants' science teaching self-efficacy (PSTE) and outcome expectancy (STOE) (Riggs & Enochs, 1989). Reliability coefficient for the PSTE and STOE were found to be 0.87 and 0.72 respectively (Bleicher, 2004). Shapiro-Wilk normality test indicated data were not normally distributed, therefore nonparametric statistical analyses were used. The Wilcoxon matched pair signed-ranks test was used to compare related samples. The Kruskal-Wallis one-way analysis of variance was used to compare group mean changes among the four models. Where statistical differences were found using the Kruskal-Wallis test, a Mann-Whitney U post hoc analysis was used to determine statistically significant differences between groups.

Results and Discussion

Content Analysis of Agendas

The agendas for each model were analyzed for inclusion of effective practices for professional development (Garet, 2001). All three models included on-going focus on science content knowledge and science careers, integration of educational technology, instruction on general and specific pedagogy, coherence with standards, and active learning techniques including observing expert teaching, planning for use, and presenting to peers. Instructional time and content for each model are listed in Tables 2 and 3 respectively.

The F2F model included a 2.5-hour teaching experience at a space science museum day camp for elementary students. Preparation and planning of lessons was conducted in the evenings at the participants' hotel. The Extended F2F model included a 2-hour teaching experience at a local elementary school. Additionally, the Extended F2F participants participated in a 45-minute peer teaching experience that was video recorded. Participants later reviewed and reflected on their videos to improve their teaching practice.

Table 2.
Summary of PSTI instructional time

Delivery Mechanisms	Time			
	F2F	Extende dF2F	Hybrid 1	Hybrid 2
In-person experience length (days)	5.5	8.5	5	5
In-person experience total instructional time (minutes)	291 0	3450	2630	2630
In-person experience daily instructional time (minutes/day)	529	431	436	436
Online experience instructional minutes before in-person experience	0	0	360	420
Online experience instructional minutes after in-person experience	0	0	60	30

Table 3.
Summary of PSTI content as determined by agenda analysis

Activities	PSTI Model			
	F2F	Extended F2F	Hybrid 1	Hybrid 2
Elementary Teaching Experience	✓	✓		
Science Content				
Force and motion	✓	✓	✓	✓
Solar system	✓		✓	✓
Living and working in space	✓	✓	✓	✓
Earth science	✓		✓	✓
Radiation			✓	✓
Engineering design	✓	✓	✓	✓
Pedagogy				
5E lesson planning	✓	✓	✓	✓
Inquiry	✓	✓	✓	✓
Problem-based learning		✓		
Educational technology	✓	✓	✓	✓

note: ✓= included in the model

Participants' Perceptions of the Impact of PSTI

Table 4 describes the five themes revealed by analysis of participants' responses to open-ended survey questions. The table also provides a synopsis of trends across the four models.

Science Teaching Self-Efficacy and Outcome Expectancy

Results of the Wilcoxon matched-pairs signed ranks test analysis of the STEBI-B are listed in Table 5. Statistically significant differences were found for the F2F model on both the

Table 4.
Participants' perceptions of the impacts of PSTI

Theme	Synopsis	Example
Valuable experience	Participants in all four models felt PSTI was a valuable experience and worthwhile.	I will definitely recommend the PSTI training, the information and resources provided are extremely valuable and directly relate to the classroom and student engagement.
Felt more prepared to teach STEM topics	Participants in all four models reported feeling more prepared to teach STEM topics and learned methods to engage and inspire students in STEM learning.	Prior to the workshop I didn't think I would be prepared to teach STEM or science in the classroom. But now I am totally confident of my ability to enrich the minds of young learners because of the program.
Appreciated NASA STEM education resources	Participants in all four models reported gaining knowledge of how NASA supports STEM education and resources available to educators.	I never knew that NASA even had resources I felt like a whole new world opened up to me. I also didn't not feel like I could teach science and now I feel very equipped.
Increased STEM content knowledge	Participants in all four models perceived they gained STEM content knowledge.	This workshop really helped me to increase my knowledge of each of the stem fields and helped to eliminate/reduce my anxiety about teaching these fields.
Intense experience	Some participants in the F2F and Hybrid models felt PSTI was an intense experience and disorganized at times.	Perhaps having the workshop longer like two weeks so the days aren't so rushed or crammed it can be a bit overwhelming. The days are intense with lots of speakers and activities.

PSTE and STOE subscales and the effect sizes of both increases were large. The Extended F2F and Hybrid 2 had statistically significant increases in the PSTE, but not for the STOE. The effect size for the Extended F2F PSTE increase was large, however the effect size for Hybrid 2 PSTE increase was medium. Hybrid 1 did not have statistically significant difference on the PSTE nor on the STOE.

Kruskal-Wallis test detected a statistically significant difference between the change in PSTE scores for all four models [H = 15.788 (3, N = 113), p = .001)], the effect size was calculated to be large (r = 1.48). Mann-Whitney U post hoc indicated the difference can be attributed to the variances between the F2F and Hybrid 1 [U = 253.50, p <.001], the Extended F2F and Hybrid 1 [U = 86.00, p = .009], and the F2F and Hybrid 2 [U = 257.00, p = .035].

Kruskal-Wallis test also detected a statistically significant difference between the change in STOE scores for all three models [H = 10.004 (3, N = 113), p = .019)], the effect size was calculated to be large (*r* = 0.941). Mann-Whitney U post hoc analysis indicated the difference can be attributed to the variance between the F2F model and Hybrid 1 [U = 345.50, *p* = .012] and the F2F and Extended F2F [U = 382.00, *p* = .017].

Table 5.
Changes in PSTs' scores on the Science Teaching Efficacy Beliefs Instrument (STEBI)

	Pretest			Post-test					
Subscale	Min.	Max.	Mdn	Min.	Max.	Mdn	Z	p	r
F2F (n=63)									
PSTE[1]	30.25	63.00	50.00	42.00	65.00	59.00	-6.60	<.001*	0.83
STOE[2]	20.00	50.00	38.00	31.00	49.00	42.00	-5.17	<.001*	0.65
Extended F2F (n=19)									
PSTE[1]	36.00	63.00	51.00	51.00	65.00	60.00	-3.75	<.001*	0.86
STOE[2]	36.00	49.00	39.00	35.00	49.00	40.00	-0.77	.444	n.s.
Hybrid 1(n=18)									
PSTE[1]	37.00	60.00	52.00	36.00	65.00	52.00	-1.17	.243	n.s.
STOE[2]	35.00	43.00	39.00	33.00	47.00	40.00	-1.17	.244	n.s.
Hybrid 2 (n=13)									
PSTE[1]	43.00	62.00	51.00	48.00	65.00	54.00	-2.40	.017*	0.67
STOE[2]	36.00	45.00	39.00	36.00	49.00	41.00	-1.76	.079	n.s.

[1]Personal Science Teaching Efficacy; [2]Science Teaching Outcomes Expectancy. *The difference in the participants' responses were statistically significant, $p < .05$. The range of possible scores on the PSTE is 13-65; The range of possible scores on the STOE is 10-50.

Attitudes Towards STEM and Teaching STEM

In addition to the STEBI-B, participants responded to survey questions asking them to rate their attitudes towards science and teaching science before and after participating in PSTI. Wilcoxon signed-ranks test found statistically significant gains in interest in science and science teaching within each model. Kruskal-Wallis test indicated no statistically significant difference between the change in interest in STEM for all four models [H = 0.058 (3, N = 108), n.s.] nor between change in interest in teaching STEM [H = 0.117 (3, N = 108), n.s.].

Implications

Overall, all four PSTI models appear to have increased participants' interest in science and science teaching. Participants in all four models perceived PSTI was a valuable experience and felt more prepared to teach STEM topics. Participants in all four models expressed an appreciation for NASA STEM education resources and perceived that PSTI had increased their STEM content knowledge. However, participants in the F2F and both Hybrid models felt PSTI was an intense experience and they did not have enough time to reflect on learning and translate learning into their teaching practice. Participants in the Extended F2F model did not express this feeling, which may indicate the longer in-person experience and ability to practice lessons with classroom students gave participants time to reflect on learning and translate learning into their teaching practice.

Increases in science teaching self-efficacy with large effect sizes were detected for both the F2F and the Extended F2F models. An increase in science teaching self-efficacy was also detected for Hybrid 2, however the effect size was medium. No statistically significant difference in science teaching self-efficacy was detected for Hybrid 1. These results may indicate providing an opportunity for PST to incorporate new learning into lesson plans and participate in an authentic teaching experience may positively influence science teaching self-efficacy. Additionally, the arrangement of the online and in-person experiences may influence self-efficacy outcomes. More online instructional minutes prior to the in-person experience may positively influence science teaching self-efficacy. Small sample sizes within each model limit the generalizability of these findings. More research is needed to more thoroughly investigate professional development delivery models and their impact on teacher learning.

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ELEMENTARY TEACHERS' ENGINEERING SELF-EFFICACY AND ENGINEERING TEACHER EFFICACY

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Research indicates that teacher efficacy influences student achievement and is situation specific. With the NGSS calling for the incorporation of engineering practices into K-12 classrooms, it is important to identify teachers' engineering teaching efficacy. The purpose of this study is to identify K-5 teachers' engineering self-efficacy and engineering teaching efficacy. Results indicate that elementary teachers have low engineering self-efficacy and low teacher efficacy related to engineering pedagogical content knowledge. Significant differences existed in self-efficacy levels based on gender, ethnicity, Title I school status, and grade level taught.

Introduction

The United States has become increasingly dependent on technology, which has led to an increased demand for workers in science, technology, engineering, and mathematics (STEM) fields and STEM literate citizens *(International Technology Education Association, ITEA, 2007)*. To address these concerns*, A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Research Council, NRC, 2012) identified key scientific and engineering practices that all students should learn during K-12 education; this framework was used to develop the *Next Generation Science Standards (NGSS)* (NGSS Lead States, 2013). The *NGSS* call for the infusion of engineering practices into K-12 science classroom; however, we know very little about how prepared elementary teachers are to successfully teach engineering standards.

Objectives of the Study

The overall objective of this study was to gain information related to K-5 teachers' preparedness to implement the engineering standards contained within the *Next Generation Science Standards.* More specifically, the current study sought to answer the following research questions:

1. How self-efficacious are in-service elementary teachers in their knowledge of engineering and engineering design? Are there differences among different demographic groups?

2. How self-efficacious are in-service elementary teachers in their abilities to teach engineering and engineering design? Are there differences in engineering teacher efficacy among different demographic groups?
3. Is there a correlation between teachers' engineering self-efficacy and their familiarity with engineering?
4. Is there a correlation between teachers' engineering teaching self-efficacy and their familiarity with engineering?

Related Literature

Self-efficacy refers to one's belief in his or her ability to produce a desired outcome. Albert Bandura (1977) described self-efficacy as consisting of two dimensions – efficacy expectation and outcome expectancy. Efficacy expectation is defined as "the conviction that one can successfully execute the behavior required to produce outcomes" and outcome expectancy is defined as "a person's estimate that a given behavior will lead to certain outcomes" (Bandura, 1977, p. 193). Self-efficacy develops from four information sources: performance accomplishments, vicarious experiences, verbal persuasion, and emotional arousal (Pajares, 2002; Bandura, 1977, 1989). Personal accomplishments, the most powerful of the four sources, are a result of personal successes and failures that result from completing a specific behavior. Vicarious experiences impact self-efficacy when an individual witnesses a peer's success or failure at a certain behavior. Additionally, individuals may be verbally persuaded into believing they will succeed in a given behavior, especially if they view the persuader as credible. Finally, emotional arousal, such as fear, anxiety, or excitement may impact the way individuals view their capabilities.

Teacher efficacy can be defined as a teacher's belief in his or her ability to influence student learning (Guskey & Passaro, 1994). Gibson and Dembo (1984) grounded their studies of self-efficacy in Bandura's two dimensions of self-efficacy – outcome expectancy and efficacy expectation – and developed the Teaching Self-efficacy Scale (TES). The TES instrument consists of two subscales – General Teaching Efficacy (GTE) and Personal Teaching Efficacy (PTE). PTE is a teacher's belief that he or she can elicit student learning, while GTE is a teacher's belief that external factors, such as home life, limit a teacher's ability to bring about student learning. Previous research indicates that higher teacher efficacy is associated with higher student achievement and greater teaching effort and persistence in difficult situations (Tschannen-Moran, Woolfolk Hoy, & Hoy, 1998). Teacher efficacy is situation specific (e.g.

grade level, subject matter, student characteristics) and a teacher's teaching efficacy is dependent upon their content knowledge and pedagogical content knowledge (Committee on Integrated STEM education, 2014).

Self-efficacy and teacher efficacy are situation specific (Tschannen-Moran et al., 1998), which warrants the use of different instruments when measuring self-efficacy and teacher efficacy across different content areas. Carberry, Lee, and Ohland (2010) developed the Engineering Design Self-Efficacy Instrument (EDSI) to measure individuals' self-concepts (including self-efficacy) related to engineering design. The Teaching Engineering Self-efficacy Scale (TESS), was specifically developed to measure K-12 teachers' engineering teacher efficacy (Yoon, Evans, & Strobel, 2014).

Methodology

Because no single instrument exists to answer all of the study research questions, the researcher combined questions from existing instruments and wrote new questions to create the Elementary Engineering Education Questionnaire (EEEQ). The EEEQ combines subscales from established instruments in addition to open-ended researcher-generated questions. This study will focus on the following subscales from established instruments: the *Self-efficacy* subscale from the EDSI (Carberry et al., 2010); the *Engineering Pedagogical Content Knowledge Self-efficacy, Engineering Engagement Self-efficacy, Engineering Disciplinary Self-efficacy, Engineering Outcome Expectancy*, and *Overall Teaching Engineering Self-efficacy* subscales from the TESS (Yoon et al., 2014); and the *Familiarity with Design Engineering and Technology* subscale from the Design Engineering and Technology Survey (DET; Hong, Purzer, & Cardelal, 2011). The *Familiarity with DET* subscale was included to gather data on how familiar participants were with engineering, as assessed by previous engineering experiences and coursework.

After two rounds of field testing, with a total of 32 K-5 school teachers, the final EEEQ instrument was entered into Qualtrics and a link was emailed to all Oklahoma K-5 public school teachers and completed by 542 participants who were responsible for the science instruction of their students. Tables 1 and 2 present the demographics for the sample. Overall, the sample was representative of the state population in regards to geographic distribution of teachers, gender, education level, grade level taught, and years of teaching experience. Participant responses on the EEEQ were transferred to SPSS and analyzed. The DET and TESS subscale data were analyzed to yield frequencies of respondents choosing each

Table 1.

Demographics of Oklahoma teacher population and study sample.

	Population		Sample			Population		Sample	
	Number	Percentage	Number	Percentage		Number	Percentage	Number	Percentage
Geographic Region					*Work Experience*				
1	670	4.03	26	4.80	1 to 5	4926	29.63	163	30.07
2	1181	7.10	48	8.86	6 to 10	3501	21.06	111	20.48
3	3538	21.28	159	29.34	11 to 15	2506	15.07	85	15.68
4	2180	13.11	55	10.15	16 to 20	2224	13.38	69	12.73
5	1049	6.31	18	3.32	21 to 25	1613	9.70	48	8.86
6	1384	8.32	37	6.83	26 to 30	912	5.49	38	7.01
7	1058	6.36	30	5.54	31 to 35	534	3.21	15	2.77
8	5567	33.48	169	31.18	36-40	323	1.94	10	1.85
Gender					over 40	88	0.53	3	0.55
M	698	4.20	16	3.00	*Certification Type*				
F	15929	95.80	526	97.00	Traditional	15951	95.93	491	90.59
Education Level					Nontraditional	676	4.07	51	9.41
Bachelor's	13090	78.73	381	70.30	*Grade Level*				
Master's/Education Specialist	3498	21.04	157	28.97	K	3176	19.10	91	16.79
Doctorate	36	0.22	4	0.74	1	3638	21.88	98	18.08
N/A	3	0.01	0	0.00	2	3601	21.66	102	18.82
					3	3658	22.00	112	20.67
					4	3370	20.27	120	22.14
					5	3527	21.21	98	18.08

Table 2.

Ethnicity and Title I school status study participants.

	Number	Percentage
Do you teach in a Title I school?		
Yes	432	79.70
No	84	15.50
Don't Know	26	4.80
Ethnicity		
African American	5	0.92
Native	42	7.75
Hispanic	13	2.40
Asian or Pacific Islander	4	0.74
White	453	83.58
More than One	16	2.95
Other	8	1.48

response category. As suggested by Carberry et al. (2010), question 1 of the EDSI was used to determine a participant's self-efficacy towards conducting engineering design (ED) and questions 2 through 9 of the EDSI were averaged to determine each participant's engineering design process (EDP) score. Pearson correlation coefficients were generated to determine if relationships exist between familiarity with DET and engineering self-efficacy or between familiarity with DET and teaching engineering self-efficacy. Researchers used an ANOVA to determine if any significant differences existed on subscale scores of different demographic groups including gender, ethnicity, grade level taught, education attainment level, pathway to certification, geographic region, and years of teaching experience.

Results and Discussion

Descriptive statistics for instrument subscales are presented in Table 3. The minimum and maximum scores in Table 3 provide the range of possible scores for each subscale. The EDSI is used to measure participants' engineering self-efficacy, with the EDSI ED measuring participants' self-efficacy for conducting engineering design and the EDSI EDP measuring the level of self-efficacy related to completing each step of the engineering design process. The mean score of 31.97 (SD = 28.49) on the EDSI ED and 39.80 (SD = 27.34) on the EDSI EDP indicates that participants have low self-efficacy related to conducting engineering design and completing each step of the engineering design process. Together, these values indicate that elementary teachers have low self-efficacy related to their personal abilities to engage in engineering design. If teachers have low self- efficacy related to personally engaging in engineering design, they may refrain from using engineering design activities with their students.

Table 3.

Descriptive Statistics for Instrument Subscales

Instrument Subscale	Minimum	Maximum	Mean	Std. Deviation
EDSI				
ED	0	100	31.97	28.49
EDP	0	100	39.80	27.34
TESS				
PCK	1	6	3.52	1.35
Engagement	1	6	4.44	1.47
Disciplinary	1	6	4.70	1.40
Outcome	1	6	4.07	1.32
Total	4	24	16.70	5.98
DET				
Familiarity	7	35	13.80	6.37

The TESS measures participants' teaching engineering self-efficacy. While participants had relatively low engineering self-efficacy, as indicated by the EDSI, their teaching engineering self-efficacy was higher. Subscale scores above 4.0 indicate that participants have positive teaching engineering self-efficacy. TESS PCK measures a teacher's pedagogical content knowledge related to teaching engineering. Notably, a far greater number of participants selected negative responses with regard to PCK, suggesting that teachers' had lower self-efficacy for TESS PCK than for the other TESS subscales. The lower score on the TESS PCK may indicate that while teachers feel they have the classroom management skills and teaching strategies required to successfully engage, discipline, and motivate students in their classroom, they feel less secure in their knowledge of engineering and which engineering resources to use with their students. The low scores of the DET Familiarity subscale (M = 13.80, SD = 6.37) suggest that participants had little experience with engineering or exposure in engineering coursework or professional development.

Differences between demographic groups

One-way ANOVA and post hoc tests were used to determine if differences existed in engineering self-efficacy or engineering teaching self-efficacy based on participant gender, ethnicity, grade level taught, education attainment level, pathway to certification, years of teaching experience, and Title I school status. Significant differences were found for grade level, gender, Title I school status, and ethnicity, however no significant differences were found for education attainment level, pathway to certification, or years of teaching experience.

Grade Level

NGSS breaks the engineering design standards into two grade bands: kindergarten, first, and second grade (K-2) and third, fourth, and fifth grade (3-5). Teachers were placed into one of the grade bands based on current grade taught. Teachers who taught within both grade bands (e.g., teaches 2nd and 3rd grades; n=18) were not included in the current analysis. The results of the one-way ANOVA and Welch tests revealed that teachers in the 3-5 band had significantly higher EDSI ED scores (M = 37.11, SD = 29.38) than teachers in the K-2 band (M = 26.29, SD = 26.12), F (1, 522.86) = 19.96, p<.001, η^2 = .04. Grade 3-5 teachers also had significantly higher EDSI EDP scores (M = 43.50, SD = 25.91) than K-2 teachers (M = 35.55, SD = 25.91), F (1, 523) = 11.40, p = .001, η^2 = .02). This is not surprising, given that trend toward departmentalization at the upper elementary level, where teachers with more experience and training in math and science are responsible for teaching those subjects.

Gender

Female participants had significantly lower scores on the EDSI ED (M = 31.18, SD = 27.81) than male teachers (M = 56.47, SD = 38.07), F (1, 16.56) = 7.38, p = .015, η^2 = .02. Female teachers also had significantly lower EDSI EDP scores (M = 39.24, SD = 27.06) than male teachers (M = 57.21, SD = 31.11), F (1, 541) = 7.19, p = .008, η^2 = .01. The lower EDSI scores indicate that female teachers have lower engineering self-efficacy than their male counterparts, and the TESS PCK indicates that female teachers have less self-efficacy related to their engineering pedagogical content knowledge than male teachers. There was no significant difference between genders on the engagement, disciplinary, and outcome expectancy TESS subscales. Gender role socialization, often initiated during infancy, and parental expectations influence children's perceptions of their abilities (Eccles, 2007), and can result in females having fewer mastery experiences with math and science related activities than males (Hyde, 2007), thus reducing the opportunities to build self-efficacy in STEM related areas.

Title I school status

Twenty-six teachers did not know the Title I status of their schools and were not included in this analysis. Teachers working in Title I schools had significantly lower scores on EDSI ED (M = 30.83, SD = 27.85), than their peers who did not teach at Title I schools (M = 40.48, SD = 28.66), F (1, 514) = 8.03, p = .005, η^2 = .02. Title I teachers also had significantly lower EDSI EDP (M = 38.99, SD = 27.84), scores than non-Title I teachers (M = 46.71, SD = 24.53), F (1, 128.23) = 6.66, p = .011, η^2 = .01. The results indicate that Title I school teachers had lower engineering self-efficacy and teaching engineering self-efficacy. The increased demands of teaching in a Title I school (e.g. fewer resources, greater teacher to student ratio) could explain some of the observed self-efficacy differences.

Ethnicity

One participant chose not to report ethnicity and was not included in the analysis. The only significant difference due to ethnicity was on the EDSI EDP subscale (F (6, 540) = 2.23, p = .039, η^2 = .02). Post hoc Fisher's LSD tests indicated that African American participants scored significantly lower than both Hispanic (mean difference = -28.98, p = .043) participants and participants reporting more than one race (mean difference = -32.41, p = .02). Additionally, White participants scored significantly lower than participants reporting more than one race (mean difference = -16.68, p = .016). The reason for these differences is not fully understood.

Correlation

Table 4 displays Pearson Correlation values for all instrument subscales. Participants' familiarity with engineering, as measured by the DET familiarity subscale, was significantly and positively correlated with all EDSI and TESS subscales, which could indicate that teachers who are more familiar with engineering and what engineers do have higher engineering self-efficacy and engineering teaching self-efficacy.

Table 4.

Pearson Correlation Values for Instrument Subscales

Instrument Subscale	EDSI ED	EDSI EDP	TESS PCK	TESS Engagement	TESS Disciplinary	TESS Outcome	TESS Total
EDSI EDP	.85**	-					
TESS PCK	.21**	.25**	-				
TESS Engagement	.19**	.24**	.78**	-			
TESS Disciplinary	.15**	.21**	.57**	.77**	-		
TESS Outcome	.22**	.27**	.65**	.69**	.66**	-	
TESS Total	.22**	.28**	.86**	.93**	.86**	.85**	-
DET Familiarity	.55**	.55**	.55**	.46**	.35**	.41**	.50**

**Significant at $p < 0.01$

Implications

Teacher efficacy impacts the instructional approaches teachers use in the classroom and student achievement. Understanding the level of engineering self-efficacy and teacher efficacy elementary teachers bring to the classroom is important when identifying their professional development needs. Teachers in the current study had low engineering self-efficacy and engineering teacher efficacy related to engineering pedagogical content knowledge. This could indicate that teachers need mastery experiences (Bandura, 1977) in the area of engineering design and teaching engineering in order to improve their teacher efficacy and effectiveness in the classroom. This could be accomplished through the development of preservice coursework and in-service workshops specifically devoted to engineering education. While the current study points to the need of mastery experiences for teachers, further research is needed to determine the specific types of mastery experiences and professional support that K-5 teachers need in order to successfully implement the engineering components of *NGSS* into their classrooms.

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TEACHER CANDIDATES AND STEM-BASED EFFICACY: A PILOT STUDY

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Elementary classroom teachers often struggle with teaching math and science content. A great deal of research has identified potential strategies to address their struggles with content and to increase science and math self-efficacy in teacher candidates/pre-service teachers. This pilot study was undertaken to determine the effect of including one specific STEM unit to existing elementary science and math methods courses. After participating in an enriched experience that would serve as a model to carry forward into future practice, teacher candidates should provide evidence of improved self-efficacy with regard to STEM-based (particularly science) planning and teaching.

Introduction

Elementary classroom teachers exert tremendous influence on their students' attitudes with regard to academic content (Bursal, 2010). While still training to enter the elementary teaching arena, many teacher candidates report low self-efficacy when asked to predict their ability to effectively teach, particularly science and math, academic content (Czerniak & Shriver, 1994; and Enochs, Sharmann & Riggs, 1995). Research targeting practicing teachers who report science and/or math low self-efficacy also indicates that elementary teachers will avoid innovative teaching strategies that promote active student engagement when delivering science and/or math academic content (Schoenberger & Russell, 1986; Huinker & Madison, 1997; and Czerniak, 1990). Rather than risk exposing their perceived and actual shortcomings, teachers will rely upon text-based instruction or lecture to intentionally reduce student inquiry (Gresham, 2008; Swars, Danne & Giesen, 2006; and Swards, Smith, Smith & Hart, 2009) in an effort to avoid what would uncomfortable and potentially embarrassing situations for the teacher.

With the current push to include more STEM instruction in earlier elementary grades, it is imperative that teacher candidates be introduced to strategies that favor effective teaching once they are in their own classroom settings (Lardy & Mason, 2014). It is also quite likely that given the average age of teacher candidates, they were students in classrooms that were subject to repeated high-stakes assessment in science and math, as well as other academic content. As a result, the teacher candidates' experiences with hands-on inquiry and project-based learning may be limited. It is quite possible that they may be expected to provide their students with enriched, integrated experiences that they never had as students.

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Purpose of the Study

This pilot program was implemented in a small north central Texas college of education. The Educator Preparation Program offers two basic degrees that account for over 95% of enrollees – EC-6 generalist certification and 4-8 content specialists (science, math, social studies or ELAR). The EC-6 generalist teacher candidates are the largest group, typically 75% - 80% of the graduating class each semester (averaging around 120 teacher candidates annually).

The questions that guided this research were:

1. How does a STEM-based learning experience affect teacher candidates' self-efficacy regarding science instruction?
2. How does a STEM-based learning experience affect teacher candidates' self-efficacy regarding mathematics instruction?
3. How does a STEM-based learning experience affect teacher candidates' self-efficacy regarding interdisciplinary instruction?

For the purposes established herein, the third question is the focus of this research paper. Therefore, only data collected and evaluated in light of that question are included.

The focus of research question 3 was to gauge changes in self-efficacy of EC-6 generalist teacher candidates as they experienced a STEM-based unit that was collaboratively taught through their science and math elementary methods courses. While concurrently enrolled in the science and math methods courses, the teacher candidates completed an interdisciplinary unit that was designed to serve as a model for similar efforts in their own future classroom settings. By selecting a singular historical event, the teacher candidates considered the collective influences of science, technology, engineering, and math in the development of the kaleidoscope. Through in-depth instruction that carried across both methods courses, they were introduced to project-based learning and had the opportunity to consider how each of the STEM elements was necessary for a more complete understanding of the kaleidoscope. Following completion of the kaleidoscope unit, the teacher candidates were assigned small groups of 5th grade students to present the same interdisciplinary (STEM) content. Data with regard to self-efficacy and their interdisciplinary teaching were gathered and evaluated for potential gains.

Related Literature

Individuals will naturally judge their ability to perform at given tasks based upon their self-perceptions. When teachers engage in this tendency, labeled by Bandura as “self-efficacy” (1986), they predict their expectations regarding their ability to teach, and to impact student learning, with desired (or less desired) outcomes (Tschannen-Moran & Hoy, 2001). Once established in the classroom, teacher self-efficacy is not likely to change significantly (Tschannen-Moran & Hoy, 2001). However, research indicates that teacher candidate self-efficacy may be more malleable and increases in self-efficacy are possible with effective professional development opportunities (Hoy & Spero, 2005).

Studies indicate that the single greatest factor influencing students’ attitudes toward science and mathematics is the classroom teacher (Bursal, 2010). As a result, elementary classroom teachers are of utmost importance not only because they represent the first “formal” teachers that young students encounter, but also because they are expected to teach all subjects well (Bauer & Toms, 1990; Ramey-Gassert & Shroyer, 1992; and Sherwood & Westerback, 1983). Not surprisingly, research has confirmed that teachers are attracted to areas of competence and find it more comfortable to present content with which they personally perform well (Parajes, 1992). Further, feelings of confidence are likely to translate into positive attitudes toward teaching those content areas. Reports of high self-efficacy are also predictive of innovative teaching strategies and student motivation (Wenner, 2001; Guskey, 1988; Scribner, 1999; Tschannen-Moran & McMaster, 2009; and Czerniak & Shriver, 1994). On the other hand, teachers often avoid (even when the curricula are required) teaching that which makes them feel less confident or competent (Schoenberger & Russell, 1986). With regard to mathematics teaching, teachers with lower levels of self-efficacy are more likely to use teacher-directed strategies including lectures and textbook readings (Czerniak, 1990) in order to compensate for efficacy beliefs likely tied to math anxiety (Gresham, 2008; Swars, Danne & Giesen, 2006; and Swars, Smith, Smith & Hart, 2009). Elementary classroom teachers with low science self-efficacy may devote little (or no) time to science instruction. Due to a perception of lesser importance when compared with academic content such as reading and math, science instruction is often presented using similar didactic teaching strategies to avoid dealing with content which holds little personal appeal or conceptual understanding on the part of the teacher (Huinker & Madison, 1997; Bauer & Toms, 1990).

To further research and effectively address the low self-efficacy in both science and math, efforts were made in the late 20th century to develop and establish instruments designed to measure teacher candidate efficacy beliefs – the Science Teacher Efficacy Belief Instrument or STEBI (Enoch & Riggs, 1990) and the Mathematics Teaching Efficacy Beliefs Instrument or MTEBI (Enochs, Smith & Huinker, 1992). Since their initial development and release, both instruments have been revised, validated and used extensively in U.S. and international teacher training programs for pre- and post-assessment of self-efficacy and changes in those measures. At the time of this study, there was no similarly vetted instrument available to measure self-efficacy with regard to STEM-based instruction.

It should be expected that teacher candidates, while still in the role of students, might be highly influenced by the experiences they have in methods courses. STEM education represents a major milestone in interdisciplinary project-based learning with the fundamental goal of including science, technology, engineering, and mathematics principles as they are applied to real-world settings. Project-based methods coursework allows students to expand, model and apply their content knowledge uniquely (Wilhelm, 2014). By providing teacher candidates opportunities to further develop conceptual understandings of science and math in project-based settings, they are allowed multiple opportunities to explore and develop various strategies and technologies that scaffold learning in practical applications (Krajcik & Blumenfeld, 2006; and Singer, Marx & Krajcik, 2000). STEM education can carry the project-based learning design one step further, allowing for the inclusion of other academic content including but not limited to art, language arts, music and social studies. Through effective inclusion, teachers increase the number of lens through which students can see and understand connections in the world they inhabit.

Methodology

Data for this project would be considered wholly qualitative in nature. The data included classroom discussions, discussion board entries, personal interviews, focus groups and electronic journal entries. Interviews, focus groups and class discussions were conducted both before and after the 5th grade small group teaching sessions. Discussion boards and journals entries were collected three times – before and after methods instruction regarding the discrete content they were to teach and after teaching their small groups.

Two sections (*n*=20 teacher candidates) were enrolled in the elementary science and elementary math methods courses and agreed to participate in the pilot study. Each professor introduced content that was relevant to understanding the function of a kaleidoscope – properties of light, angles of incidence and reflection, geometric principles and practical applications of measurements. The teacher candidates were charged with researching the history of kaleidoscopes (inventor, social/economic factors of the time, development of materials necessary for construction, etc.). The teacher candidates were assigned to small groups with specific research topics as described above; each group's research was then presented to and discussed in each of the classes.

Data were collected before and after specific junctures during the semester. Individually, the participants responded to 3 electronic journal prompts that were provided before and after 3 separate periods of instruction involving kaleidoscopes and related science and math concepts. The teacher candidates also participated in focus groups scheduled after individual interviews, online journal responses and research group presentations had been completed. Using similar questions and following up on open-ended journal prompts, the goal of each focus group was to encourage more discussion and deeper reflection. The focus groups were electronically recorded, transcribed and verified by member checking. Likewise, classroom discussions were scheduled twice – prior to and after the teaching session with the 5th grade students. Those discussions were also electronically recorded, transcribed and also verified through member checking.

Cross-case and pre/post analysis as well as triangulation of the data were used to determine emergent themes and potential gains in self-efficacy with regard to interdisciplinary teaching beliefs. The themes included the nature of interdisciplinary teaching, potential need for collaboration and greater student engagement.

Results and Discussion

While the original research question involved teacher self-efficacy, three major themes (related to efficacy) emerged from analysis of the data included:

1. the nature of interdisciplinary (particularly STEM) units/lessons;
2. the desirable traits of successful interdisciplinary teachers; and
3. the likelihood of increased student motivation when teaching with an interdisciplinary format.

The first theme was especially important as early assessments indicated that participants consistently held the misconception that a good interdisciplinary unit/lesson required that teacher to be an expert in all fields. A typical comment, "A teacher must be knowledgeable in each of the STEM content areas," would indicate that unless one is knowledgeable in all areas, then interdisciplinary lessons ought not be attempted. By the end of the study, more typical comments included, “An effective STEM teacher needs to be well-rounded and possess sufficient background information in each subject area, be organized and creative”.

The second theme, revealed through electronic journals, focus groups and personal interviews, indicated personal characteristics that favor successful interdisciplinary teaching. Two basic traits that held throughout were, “A (successful interdisciplinary) teacher needs to be willing to work with other teachers and experts in the field” and “A teacher does not have to equally qualified in all content areas – they just need to be willing to learn content, if they need to, in order to be able to teach it correctly to the students” and “they need to be learners at heart”.

Greater student engagement, the third theme, reinforces teachers’ efforts and helps to strengthen efficacy overall. The participants repeatedly cited greater student engagement as an expected outcome; other reasons for including interdisciplinary units/lessons throughout a school year included, “Students may not be able to see connections between content areas unless they are clearly linked and presented to them”, “Lessons that incorporate the different content areas in everyday life may keep them more interested than they are in the single content areas”, “Keeping students engaged while they were taught reduced behavior management issues”, “Interdisciplinary lessons may let students see difficult content (for example, a math concept) from a different perspective and thereby gain greater understanding”, and “When students are taught from different perspectives, more learning styles are probably addressed – that likely increases the chances for all students to succeed.”

Implications

The results from this pilot study will be combined with data that are be similarly gathered for two additional semesters. Based on data gathered thus far, it would appear that specific interdisciplinary methods training for EC-6 teacher candidates should be included in their elementary methods courses. Elementary teachers will increasingly find STEM curricula included in early grades’ elementary science and math content standards across the country. Professors of those content and methods courses should serve as role models for collaborative teaching as teacher candidates should experience interdisciplinary learning. Over 80% of the participants in this study indicated they could not remember a single interdisciplinary experience during their K-12 enrollment. Instead, they agreed that they “felt like they had spent all of those years learning to take multiple choice tests", a less than subtle reference to high-stakes testing and accountability requirements.

An additional area for further investigation might be measurements of self-efficacy and factors (beyond content knowledge) that affect teacher candidate/preservice teacher beliefs. EC-6 teacher candidates are required to be proficient in all content areas as they usually represent the sole agent of academic delivery in their classrooms and rightly so. However, self-efficacy – the belief that one can be successful – can be strengthened through positive interactions, particularly collaborating when faced with teaching content that is less familiar or comfortable. Collaboration, however, is not a social skill that comes naturally to everyone. Embedded within the proposal to include interdisciplinary methods should be instruction on collaborative practice. Again, the elementary methods' professors would need to teach, model and provide time to practice these skills. Successful teachers learn to do this over time, often after they have been teaching for several years. Why not provide teacher candidates with those skills and sufficient time to practice prior to their professional entry into the classroom.

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BOLSTERING TEACHERS' STEM LITERACY VIA INFORMAL LEARNING EXPERIENCES

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STEM literacy is the ability to apply concepts from science, technology, engineering, and mathematics to solve problems that cannot be solved using a single discipline. In this qualitative research study, we examine how a robotics course in an educator preparation program that integrates informal learning experiences increase teachers' exposure to a variety of STEM learning activities and impact their STEM literacy. The results reveal that the teachers developed a deeper understanding of STEM as they participated in the informal learning environment and broadened their STEM literacy. The teachers proclaimed this experience will positively influence their instructional practice in the classroom.

Introduction

STEM literacy is not a conglomeration of the four silos that comprise STEM (i.e., science, technology, engineering, and mathematics). It does not take components of scientific literacy, technological literacy, engineering literacy, and mathematical or quantitative literacy from each of the STEM disciplines and generate STEM literacy. Instead, it involves and is nestled in the transdisciplinary integration of STEM disciplines and the tools and knowledge necessary to apply STEM concepts to solve complex problems (Balka, 2011). More specifically, STEM literacy is the ability to apply concepts from science, technology, engineering, and mathematics to solve problems that cannot be solved using a single discipline. An understanding of STEM literacy as a unique tool set to create and use knowledge of and across disciplines arise from applying the concept of literacy to disciplines individually and holistically (Mohr-Schroeder, Cavalcanti, & Blyman, 2015).

An integrated approach to STEM education is needed to prepare STEM teachers (Ostetler, 2012) to teach students in the 21st century. Prospective and in-service teachers who have opportunities to experience and apply an integrative pedagogy develop a broader meaning of STEM than those who have a degree in a single STEM discipline that incorporates a general understanding of STEM topics and how they are related (Honey, Pearson, & Schweingruber, 2014; Ostetler, 2012).

Objectives of the Study

Research has shown that more exposure to a variety of STEM opportunities will have a long-term effect on individuals and the overall STEM education community (Wai, Lubinski, Benbow, & Steiger, 2010). While research exists on how using an integrated approach to teach STEM subjects can increase student motivation and achievement, limited research exists on ways to support teacher development that integrates STEM disciplines (Honey, Pearson, & Schweingruber, 2014). The purpose of this study was to examine how a robotics course in an educator preparation program situated in informal learning experiences impacts teachers' STEM literacy.

Theoretical Framework and/or Related Literature

STEM Literacy

Prospective and in-service STEM teachers need to have content specific knowledge as well as the ability and confidence to teach across subjects in order to effectively integrate STEM learning experiences in their own classrooms (Honey, Pearson, & Schweingruber, 2014). Not only must prospective and in-service STEM teachers have knowledge of ways to integrate STEM, they need to have positive dispositions toward STEM and be STEM literate. Bybee (2010) defines STEM literacy as "the conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues" (p. 31). Zollman (2012) extends this definition and includes cognitive, affective, and psychomotor domains. Unfortunately, many people, including prospective and in-service teachers have a negative disposition toward STEM. Therefore, it is important to include cognitive and affective change strategies such as student-centered, hands-on, STEM related activities to promote more positive dispositions toward STEM (Lee & Nason, 2012).

Informal Learning Environments

Informal learning experiences provide opportunities for prospective and in-service teachers to apply what they learned in coursework in an authentic environment outside of the classroom (Jackson, Mohr-Schroeder, & Little, 2014). With this knowledge, teachers have an opportunity to reflect on their experiences and subsequently apply the lessons in ways that will transform education (Swick, 2001). Research suggests pedagogy rooted in informal learning environments grounds the learning in experience (Root, 1997) for prospective and in-service teachers. The See Blue STEM Camp is one such informal learning environment where teachers can engage in authentic tasks that will increase their STEM literacy and help them become more effective STEM teachers.

The See Blue STEM Camp

The See Blue STEM Camp is a weeklong (5 days) summer day camp for rising middle level students (incoming grades 5-8). The camp focuses on authentic hands-on sessions where students are given opportunities to engage in a variety of STEM fields. During the camp, the students participate in a daily session of Lego Robotics for three hours. Opposite Lego Robotics, students attend sessions focused on STEM content in authentic environments. For example, students would go to the biology lab to learn about human organs from a biology professor and her graduate students. All the topics and content in the See Blue STEM Camp are centered on the eight Standards for Mathematical Practice (CCSSO, 2010) from the Common Core State Standards for Mathematics and the eight science and engineering practices (NRC, 2011) from the Next Generation Science Standards. Prospective and in-service teachers participate in the camp by serving as group leaders and group helpers for the 144 middle school students attending the camp. They participate and help facilitate the authentic hands-on STEM sessions and the Lego Robotics sessions.

Methodology

This project utilized qualitative methods to answer the following research question: How does a course within an education program that integrates informal learning experiences increase teachers' exposure to STEM and impact their STEM literacy?

Population

The 32 participants in the study were graduate students in a STEM Education doctoral program, undergraduate and graduate students seeking certification in mathematics or science education (grades 8-12), and college-credit seeking high school students from a local STEAM high school program. All participants were enrolled in an introduction to robotics course at a large public university in the southeast region of the United States. The robotics course introduced fundamental concepts of robotics (e.g., basic design, function, ethics), and gave participants opportunities to explore robots, engineering concepts, engineering design, and robotics curricular material for K-12 students.

Course Structure

The robotics course was a 4-week long hybrid (some face-to-face sessions in addition to asynchronous online modules) summer course where students (a) gained familiarity with the interdisciplinary field of robotics and its growing impact on society; (b) developed the ability to direct robots using computer languages for communication; (c) gained familiarity with widely-used computer programming constructs including variables, assignment, looping, and conditional statements; (d) gained aptitude in understanding, designing, and evaluating patterns of logic and reasoning expressed as algorithms; (e) learned to practice argumentation and reflection on topics related to disciplinary content, including and especially ethics; and (f) became more comfortable and effective working in a team setting, particularly in analyzing and communicating logical and computational ideas with others.

While students learned about basic robotics communication and programming, the robot choice for the course was the EV3 Lego Robot, due to K12 school use and state competitions via the First Lego League. After building their EV3 robots, students were required to program their robots to meet various challenges. The early challenges (such as drawing a square) in the course required students to use “blocks” to program their robot to move forward, backward, and turn. “Loops” and “switches” were used for more challenging tasks to incorporate the use of sensors (e.g., program robot to sense when it was 11 inches from the wall, and then turn and return to the original position). In order to apply what they learned in the first 3 weeks of the course, the participants were required to participate in a full week of the See Blue STEM camp as teacher leaders (e.g., group leaders and group helpers) and attend daily meetings and debriefing sessions involving camp staff.

Data Collection

Data were collected over two summers throughout participants’ (henceforth, referred to as teachers) participation in See Blue STEM Camp via their robotics course. In their role as teacher leaders, the teachers accompanied and participated in the camp’s activities alongside the middle level students. The teachers were asked to complete daily reflections at the end of each day for the first four days of STEM Camp. The reflection prompts focused on what they learned at the camp, what they liked about what they learned, and what they did not like about what they learned. At the end of the camp, the teachers reflected and synthesized their growth and learning in a two-page written final reflection. In addition, the teachers participated in a semi-structured interview about their experiences working and participating in the See Blue STEM Camp.

Data Analysis

The data (written daily reflections, final reflection, and interviews) were analyzed using a data reduction approach (Miles & Huberman, 1994) along with a constant comparative method

(Glaser, 1965). Using a constant comparative approach, we compared incident-to-incident analyzing the data for similarities and differences (Charmaz, 2006).

Results and Discussion

As the teachers participated in the informal learning environment of the See Blue STEM Camp via the Robotics course, several themes emerged from their reflections and interviews. A majority of the teachers developed a better understanding of STEM, identified instructional practices that are essential for teaching, and noticed students' excitement when learning STEM content, which ultimately increased their own STEM literacy.

Understanding STEM

Prior to participating in the robotics course, a majority of the teachers did not have a clear understanding of STEM and what it looks like when students actively engage in STEM activities. All of the teachers articulated that STEM was an acronym for science, technology, engineering, and mathematics. However, it was not until after they participated in the See Blue STEM Camp via the robotics course did they come to realize the true meaning of STEM. For example, one teacher stated, "They're really are all interconnected and kinda go together" (Teacher Interview, 2015). Another teacher further elaborated that STEM is "interdisciplinary education" involving the four disciplines of science, technology, mathematics, and engineering, and you do not teach each discipline in isolation.

Since many of the teachers were primarily only confident in their mathematics abilities, as a majority were in-service or future mathematics teachers, they deepened their content knowledge in various STEM disciplines as they participated in the See Blue STEM Camp. In one session that focused on energy, the teachers were surprised to discover that cement acts like a glue to hold concrete together. The teachers had the misconception that cement dries and that is why it hardens. They were shocked to discover this in fact was not true. Instead, the cement undergoes a chemical reaction, hence why cement needs to sit untouched while it cures.

The teachers' understanding of STEM was broadened not only from the instructors' presentations, but also from the middle level students participating in the camp, particularly during the robotics sessions. One teacher stated, "I didn't truly grasp the programming side until camp actually started. I would say the kids in the camp helped me more with understanding complex programming on the EV3s than anything else did" (Teacher Final Reflection, 2014). One teacher felt uncomfortable knowing that the students were able to pick up on the technology faster than he could. He confessed, “It made me feel a little inept because of how long it took me to program the robots to do a square compared to how quickly the students could do it” (Teacher Reflection, 2014). But, a majority of the teachers were not intimidated by the students’ knowledge. The teachers were simply amazed at what the students could do and how quickly they picked up the programming language.

Once teachers had a better understanding of STEM they were excited about the different ways they could take what they learned into their classrooms. The teachers were involved in activities ranging from extracting DNA, interacting with human organs, sending a magnetic ball through PVC and a copper pipe, and geocaching and mapping using Google Earth. They exclaimed how they would like to use all of the activities from STEM Camp in their classrooms. A teacher voiced some hesitation, but realized the importance of it.

> As a mathematician, we enjoy knowing a specific algorithm to solve a given problem. As a STEM educator and student, we must embrace several methods and different attempts to reach a certain result. I am nervous about working across disciplines because I am not an out of the box thinker. Recognizing this now is beneficial to my growth. (Teacher Final Reflection, 2014)

Many of the teachers realized STEM was more about the integration of the four subjects, and the activities they participated in via the robotics course and the See Blue STEM Camp broadened their view of STEM.

Instructional Practices

The teachers mentioned the importance of the middle level students stopping and thinking about what they needed to do to in order to fix their robot. They noticed a lot of the students wanted to immediately try to fix their “robot” (i.e., programming) once the robot was not able to complete the challenge. Some of the middle level students did not take the time to stop and think about what was causing the robot to be unsuccessful in completing the challenge, and what they needed to do to come up with a solution. The teachers extended the “stop and think strategy” to their classroom. One teacher stated, “I think stopping and thinking is a good strategy for almost any task. When students are working on a math problem with context, stopping to think if their answer makes sense is one way to check their answer” (Teacher Reflection, 2014).

While many of the teachers expressed the practice of making sense of problems was necessary, the majority of the teachers stated hands-on activities keep students engaged in the lesson. From their experience with the camp, they recognized students learned more through hands-on tasks. A teacher commented, “It seems like everyone had a lot of fun with the interactive stations. It is such a simple way to get students engaged, which is something I hope to bring to my classroom in the future” (Teacher Reflection, 2014).

The teachers also gained first-hand experience on what it meant for a teacher to be flexible. They learned the importance of adapting their instruction in the moment. During the See Blue STEM Camp one of the robotics instructors had to adapt his instruction due to materials not being assembled. The teachers were glad they had the opportunity to see how to handle situations when a lesson did not go as planned. One teacher also realized he has to be more flexible in how he thinks about his teaching. He remarked, “I have had a very rigid view of mathematics and unfortunately that has influenced the way I teach. Math does not always have to be black and white, right or wrong, although there are occasions for that. I need to allow for flexibility” (Teacher Final Reflection, 2014).

Many teachers were surprised about students being at various levels. A teacher noted, “Kids working at different paces was something that blew my mind! (Teacher Reflection, 2014) They heard and discussed students in the same class can be at different levels, work at different paces, and require different amount of help. Yet, it was important for them to refrain from giving the middle level students answers to STEM tasks and provide opportunities for the students to figure out the problem. “You can guide them with good questions. There is a difference in giving the answer directly and asking probing questions to check for understanding” (Teacher Reflection, 2014).

The teachers recognized that not only were they teaching the students, the students were teaching them. “While I was teaching, I was also learning, and while the kids were learning, they were also teaching me. This is something that I think is very important for all future teachers to realize. Students will teach you just as much as you teach them” (Teacher Final Reflection, 2014).

Students’ Excitement

The teachers had an opportunity to witness the middle level students’ excitement when learning mathematics and science. They expressed that seeing students’ enthusiasm in these disciplines was rare. “I liked seeing students excited about learning! We do not see students interested in education and learning everyday, especially math” (Teacher Reflection, 2014). Many of the teachers did not expect students to be so engaged in learning and enthusiastic about learning STEM concepts, especially since many of the students did not enroll in the camp because they enjoyed the STEM disciplines.

With the excitement, the teachers noticed how persistent the students were and refused to give up even when they were unsuccessful completing various tasks. One teacher articulated, “I was impressed with the persistence of many of the groups. Even when some kids got frustrated, they refused to give up. It was awesome to see!” (Teacher Reflection, 2014).

The teachers were amazed at how the students took ownership of their learning. They stated the students would ask for help, but then would say, “never mind, I’ve got it.” The students realized they did not need the assistance of the teachers to complete the task. They recognized they could figure it out on their own. Therefore, after the students’ successful completion of each task the teachers noticed they would jump up and down, smile, cheer, and take a “walk of victory.”

Implications

The informal STEM learning experiences the teachers engaged in were aimed at providing an embedded pedagogy in order to increase STEM literacy and learning in context intended to influence delivery of STEM learning in their classrooms. It is important teacher education programs provide opportunities for teachers, both prospective and in-service, to develop and deepen their understanding of STEM literacy. As one teacher proclaimed, “I’ve had very limited experiences with STEM in general, so everything I’ve been learning has been new” (Teacher Interview, 2015). As educators we need to engage teachers so they can become STEM literate. The gains in developing content and pedagogical knowledge support the regular integration of informal learning experiences for teachers (Klanderman, Moore, Maxwell, & Robbert, 2013; Swick, 2001). When the learning experiences integrate STEM-related content, gains are possible to support STEM teaching and learning.

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THE ISSUES OF INTEGRATING DIGITIAL GAMES IN K-12 MATHEMATICS EDUCATION

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National Council of Teachers of Mathematics (2000) has emphasized the importance of integrating technology in K-12 mathematics education. This has made researchers direct their attention to digital games as an appealing method to teach K-12 students mathematics. Numerous research studies have increasingly shown that digital games are effective in improving students' performance in mathematics education. 33 out of 296 research studies were identified as appropriate and analyzed further. This study presents the current trend of research, the issues from existing research studies, and discusses the direction of future research about digital games in K-12 mathematics education.

Introduction

In the last decades, the computers have come to play an increasingly important role in all educational fields. A variety of technologies are now integrated into mathematics classrooms. This is not only because more and more students are using technology as a tool for learning, but also because educators find that implementing technology helps them incorporate varied activities to fit their student's needs. National Council of Teachers of Mathematics (NCTM, 2000) also emphasizes that technology plays an important role in teaching and learning mathematics. In the last few years, Digital Game-Based Learning (DGBL) has become one of the potential learning tools for teachers and students in K-12 mathematics. According to numerous research studies, digital games are increasingly reported to be effective in improving students' motivation and performance in mathematics education (e.g., Bai, Pan, Hirumi, & Kebritchi, 2012; Beserra, Nussbaum, Zeni, Rodriguez, & Wurman, 2014; Chen, Liao, Cheng, Yeh, & Chan, 2012; Lin, Liu, Chen, Liou, Chang, Wu & Yuan, 2013; Rayya, & Hamdi, 2001; Vogel, Greenwood- Ericksen, Cannon-Bowers, & Bowers, 2006). As educators have become interested in using computer games to improve mathematics achievement of students, the question of the effectiveness of these games has become more controversial (Bai, Pan, Hirumi & Kebritchi, 2012). Recent empirical studies on the effectiveness of digital game-based learning toward mathematics are especially sparse.

Objectives of the Study

This research aims to report on the issues found in the current studies integrating digital games in mathematics learning for students in grades K-12. To do this, this research will explore the general trend of digital game-based mathematics learning as well as the related findings from empirical researches from 2000 through 2014. Specifically, the objective of this meta-analysis study is to 1) explore studies using DGBL method for students' mathematics learning, 2) describe recent research trends, 3) examine the overall effects of digital games on mathematics education, 4) discuss issues found in the studies, and 5) suggest ideas for conducting a quality DGBL study in mathematics education.

Related Literature

Kolovou, Heuvel-Panhuizen and Koller (2013) investigated whether an online game, called *Hit the Target*, contributed to 236 6th grade students' success in solving problems with co-varying quantities within early algebra subject area. Their research showed that students benefitted from the intervention and indicated that computer games were considered as an important tool in improving students' performance in early algebra. In the meta-analysis, Vogel et al. (2006) examined 32 empirical studies to identify whether the use of a virtual reality (VR) learning game (a three-dimensional, life-like experience in which the individual's control over program) increased learning over traditional two-dimensional computer –assisted instruction (CAI). They observed that playing instructional games resulted in significantly higher cognitive gains compared with traditional teaching methods without games.

Although many researchers did find positive results using instructional computer games when learning mathematics at the elementary and secondary level, other researchers have come to different conclusions. For instance, Ke (2008) investigated if students' math test performance level improved through a game-based summer math program compared with traditional paper-and–pencil drills. Fifteen 4th and 5th grade students participated in the study. They observed that at the post-test, there was no significant effect of computer games on students' cognitive test performance (achievement) or metacognitive awareness development.

Regarding the outcomes of DGBL in general, however, a few meta-analysis studies found critical issues within the body of literature that presents positive effects of DGBL on learning. For example, Clark (2007) points out that a large portion of these studies had no control group or pre-test. There was a lack of information gathered regarding students' previous knowledge, which many educational studies usually use to measure the effectiveness of an educational intervention in student learning. In addition, after reviewing 105 instructional game studies, Hays (2005) found several concerns, including a) ill-defined terms and methodological flaws, b) findings that were not easy to generalize, c) a complete lack of evidence indicating games as the preferred instructional method, d) the diminishment of game effectiveness without debriefing and feedback, and e) the essential role of instructional support during play.

Considering the issues raised by the previous meta-analysis research on DGBL, the fundamental rationale to systematically review existing research studies that investigate the effects of DGBL in mathematics education are twofold: firstly, the amount of research in this area is constantly increasing, and secondly, future researchers can only conduct more rigorous study if they are better informed about the methodologies of previous studies. Furthermore, since the meta-analysis studies mentioned above were conducted approximately a decade ago, it is worthwhile to update the information by reviewing more recent studies. To this end, Divjak and Tomić (2011) conducted descriptive meta-analysis research investigating the impact of DGBL for learner achievement and motivation specifically on mathematics education. However, their study focused not on examining the issues of the effectiveness of DGBL, but on reporting the overall research trends, such as the nationality and the age of the existing DGBL research participants and the number of studies concerning DGBL. The current study goes one step further from the previous meta-analysis research through reviewing existing literature systematically.

Methodology

Information retrieval

In total, 296 DGBL research papers were collected through an initial online search of databases, including ERIC, PsycINFO, Social Science Citation Index, Science Citation Index, and Google Scholar. The search limitations used for the search were; 1) the research paper should have been published in a scholarly, peer reviewed academic journal; 2) the full text of the study should be provided online; and 3) the date of publication should fall into the range between January 1, 2001 and October 31, 2014. The key words used for the search were the combinations of “computer game,*” “digital game,*” and “video game,*” with “mathematics education”.

Selection Criteria

In the first stage, the title and abstract of each study were reviewed based on a set of screening criteria including a) the study should have some kind of empirical data (whether qualitative or quantitative), b) the study is about using digital (computer or video) games for instructional or learning purpose, c) participants of the study are students in regular classrooms in grades K-12, and d) the study is about mathematics education, especially students’ mathematics learning performance. Of the 296 studies that fell within these limitations, only 39 studies could be classified as empirical studies from which overall DGBL research trends in K-12 mathematics education could be analyzed. A full copy of each of 39 studies was then obtained for the second phase of screening, which is the full text evaluation.

In the second phase, two reviewers read all articles to evaluate the appropriateness of the study. In case of any uncertainty as to the eligibility a study, the two reviewers discussed and made decisions together on whether or not to include the study for analysis. After the second phase of screening, six out of 39 studies were dropped because those six studies failed to meet the criteria for the second review (e.g., no data reported in the study, not K-12 participants, not written in English, and unable to obtain the full text) even though they seemed to meet the criteria at the first phase of review. Hence, 33 research studies were identified as definitely appropriate studies and were able to be analyzed further.

Coding Framework

In order to investigate the current trend of the research studies on the use of digital games in mathematics education, 9 themes in total were established as follows; a) goal of the study, b) year of publication, c) name of the journal, d) academic field of the journal, e) expertise area of the author(s), f) research method, g) country, h) grade level of the participants, and i) NCTM content standards for mathematics.

Calculating Effect Size

First, we found that 16 research studies were not appropriate to be included for calculating the average effect size. Hence, 17 research studies were finally identified for the average effect size calculation. The second step was to obtain the effect size of each study. For the studies having explicitly the value of mean and standard deviation (SD), Wolf (1986) suggested to use the following formula to calculate the effect size of the study.

$$effect\ size\ (d) = \frac{Mean\ difference\ between\ experimental\ and\ control\ groups}{Pooled\ standard\ deviation}$$

Although all the effect size values of 17 studies were successfully obtained through the process described above, it was hard to say that each effect size has the same weight. As a solution to resolve this issue, Wolf (1986) suggested to use a weighted effect size for obtaining an unbiased estimate of the effect size *d* when conducting quantitative meta-analysis research. As a result, a weighted effect size ($\bar{d}$) was calculated using the following formula,

$$weighted\ effect\ size\ (\bar{d}) = \frac{\sum wd}{\sum w}$$

"where *d* is the unweighted effect size and *w* is the reciprocal of the estimated variance of *d* in each of the studies to be aggregated in the meta-analysis" (Wolf, 1986, p. 41). In order to estimate *w*, a formula shown below was used.

$$\text{reciprocal of the estimated variance of } d\ (w) = \frac{2N}{8 + d^2}$$

Results and Discussion

In total, 33 studies were selected for investigating the current trend of research on DGBL in mathematics education and this can be summarized as follows;

1. The research evaluating the effects of DGBL for mathematics education with empirical data has been constantly increasing since 2005(see Figure 1).
2. Considering the field of journals where DGBL studies have been published and the expertise of the authors, DGBL studies have been conducted in the field of educational technology predominantly. This result shows that the research on DGBL in mathematics education have been conducted predominately in the field of educational technology even though the major concern of such studies was about the effects of DGBL on learning mathematics.
3. More than 90% of studies (30 out of 33 studies) were conducted using quantitative and mixed research methods for investigating the effects of DGBL on mathematics education. It seems natural because DGBL is still new compared to other learning methods using technologies (e.g., Computer-Based Instruction, Computer Supported Collaborated Learning (CSCL), online learning, etc.), and so educators need to conduct a study that evaluates the effectiveness of DGBL for mathematics learning.
4. Interests in using digital games for mathematics education have become an international topic. More than half of the studies (18 studies) were conducted in the countries speaking English as their primary language (i.e., United States, Canada, Australia, and Philippines). It is not surprising that the portion of the English-speaking countries is greater than the one of non-English speaking countries. Consequently, if we included the studies written in other languages for the review, the portion of the countries would be different.
5. Two third number of the DGBL research studies were conducted with elementary school-age students. Based on this result, it can be inferred that DGBL has been primarily used in teaching and learning lower level mathematics skills.

6. The largest number of studies examined the effects of DGBL was number and operation, followed by algebra, geometry, measurement, and data analysis and probability (See Figure 2). The research interests in the effects of DGBL were mainly focused on numbers and operation, and algebra in Pre K – 12 schools.

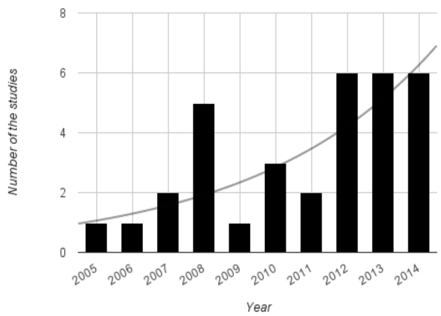

Figure 1: Years of publication

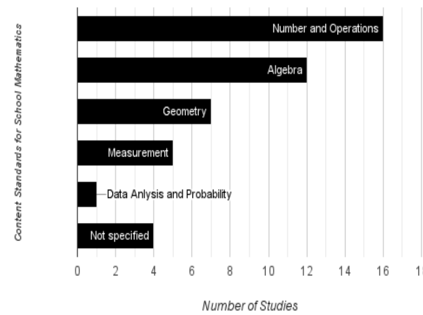

Figure 2: Number of studies by content

In order to examine the overall effects of DGBL on students' mathematics learning, weighted effect size ($\bar{d}$) for overall studies was calculated as described previously in the method section. The overall weighted effect size, which is calculated to see how much effective DGBL is on learning mathematics, was .37, which indicates moderate effect (Cohen, 1988). This number can be inferred that although the majority of DGBL research studies have positive effects on students' learning mathematics, there may be other factors for students to learn mathematics that is more effective than DGBL.

In addition to the findings, several issues regarding DGBL research in the field of mathematics education emerged through conducting this meta-analysis research. First of all, compared to the number of the studies in total, there were very few empirical research studies. Only 33 out of 296 research studies could be identified as the empirical studies which actually examined the effects of DGBL on students' learning mathematics. Second, as reported in the finding section, among 71 authors who participated in the DGBL research reviewed in this study, very low portion of authors had mathematics education background (i.e., 5 out of 71 authors, 7%). It may explain if more professional math educators in mathematics education participated in the DGBL research, the quality and applicability of the research could be heightened by discussing the effects of DGBL on mathematics education more in depth. Third, it was found that the term DGBL has been used as various meanings equivalent to the use of computer simulation, the game making activity, or even the gamification. This phenomenon might be caused by too broad definition of DGBL. Prensky (2001) defined DGBL as “any learning game on a computer or online” (p. 146). In this definition, digital games do not have to play a role as an educational media that has learning content and so yields learning outcomes. The broad definition of a term could bring an expansion of the related research in quantity. The more precise and specified the definition of a term is, the better quality the research could have. Fourth, it is necessary to expand the research focus to other content areas such as geometry, measurement, and data analysis and probability that is less studied compared to other areas like numbers and operation, and algebra in order to compare the overall effects of DGBL. Finally, most of the digital games used simpler or less complicated representations or drill-and-practice skills because the targeted game users were mostly students from elementary and middle school.

Implications

For the past 14 years, there has been a dramatic increase in empirical studies using digital games in learning mathematics. In spite of increases in research in this area, there is still a gap between DGBL that focuses on students learning mathematics. As a result, this can be problematic for both mathematics educators and students. Some of the foreseeable problems could be; not effectively integrating any digital games into mathematics learning which may results in inefficiency, waste of resources, and time. Additionally, it is even more critical for these researchers to have some training or expertise in mathematics education. Moreover, almost all of the research studies have not been investigated what mathematical proficiency (Kilpatrick, Swafford, & Findell, 2001) students can benefit while playing the digital games. Mathematical proficiency is broken down into the following five strands: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition as described by Kilpatrick et al (2001). Students would benefit if mathematics researchers can select the digital-based games related to develop more on conceptual understanding rather than focus more on procedural fluency.

In light of the above, we recommend that mathematics researchers identify what mathematical proficiency students can benefit while playing the digital games and whether they can be applied when integrating digital games for the learning of mathematics. Therefore, it is necessary and important for mathematics researchers to evaluate digital games that can be applied to learning mathematics in a more effective and efficient manner. A focus in these areas may improve DGBL on mathematics education and the overall satisfaction of students learning mathematics.

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TRANSDISCIPLINARY PREPARATION OF PRESERVICE SECONDARY MATH AND SCIENCE TEACHERS

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There is currently minimal research about transdisciplinary preparation of preservice secondary math and science teachers. This was investigated during the summer of 2015 at a week-long professional development funded by the Kentucky Center for Mathematics (KCM). The findings from the professional development are presented. Participants' beliefs and attitudes towards STEM (science, technology, engineering, and mathematics) integration were examined. The experience culminated with integrated lessons developed by the preservice teachers.

Introduction

Traditional programs for secondary education require preservice teachers to focus on one discipline and provide little to no support in linking content (Frykholm & Glasson, 2005). Yet national standards documents include making connections as a necessity (National Council of Teachers of Mathematics [NCTM], 2000; National Research Council [NRC], 1996; International Technology Education Association [ITEA], 2000). Increasing U.S. students' performance in science, technology, engineering, and mathematics (STEM) must start with improving the training of educators that will teach them these subjects. Researching attitudes and beliefs of preservice teachers is valuable since these aspects guide actions (Richardson, 1996). Maier, Greenfield, and Bulotsky-Shearer (2013) believe attitudes and beliefs must be enhanced in order to improve teachers' effectiveness. Secondary preservice teachers are likely to have positive attitudes and beliefs toward their own discipline. However, attitudes and beliefs towards STEM disciplines outside one's focus and integrated teaching should be examined.

Exploring secondary preservice teachers' dispositions toward integrated teaching is valuable since STEM content is often segregated at this level. Much of the current research focuses on elementary and middle grades preservice teachers (Adams, Miller, Saul, & Pegg, 2014; Baxter, Ruzicka, Beghetto, & Livelybrooks, 2014; Cady & Rearden, 2007; Koirala & Bowman, 2003) and less common are studies involving secondary preservice teachers (Berlin & White, 2010 & 2012; Frykholm & Glasson, 2005; and Lehman & McDonald, 1988). The literature also provides examples on coaching inservice teachers for integrated teaching (Basista & Mathews, 2002; Jost, Carter, Lipscomb, Worrell, & Shimmel, 2011; Nadelson, Callahan, Pyke, Hay, Dance, & Pfiester, 2013), but why wait until educators are already in the field before exposing them to STEM teaching?

Objectives of the Study

The Transdisciplinary Experiences for Preservice Secondary Teachers (TEPST) program sought to provide preservice secondary mathematics and science teachers models of STEM teaching and methods for implementing it into the classroom. The week-long professional learning experience included four days of faculty-led presentations, activities, and discussions and a final day consisting of a culminating experience with the preservice teachers preparing and presenting a STEM lesson in groups. The goals for this study were for the participating preservice math and science teachers to: (a) develop positive attitudes and perceptions of STEM teaching, (b) develop an appreciation for STEM content areas outside their discipline, (c) develop knowledge for collaborating with other STEM teachers, and (d) develop an understanding of the connections between science standards and mathematics standards. To accomplish these goals sessions during the professional development were designed to model effective STEM teaching as well as educate the participants in STEM content that was likely new to them.

Theoretical Framework

Learning develops as individuals take part in social interaction. Lave and Wenger (1991) describe situated learning as knowledge gained naturally within activities. Learners become members of a “community of practice” sharing common beliefs and actions. Brown, Collins, and Duguid (1989) claim collaborating and constructing knowledge in social atmospheres encourages learning. Authentic experiences are typical behaviors of the culture. “People who use tools actively rather than just acquire them…build an increasingly rich implicit understanding of the world in which they use the tools and of the tools themselves” (p. 33). Frykholm and Glasson (2005) studied preservice secondary teachers and advocate situativity for authentic learning of math and science connections.

The TEPST participants were engaged in situated learning throughout the program. The preservice teachers had varied backgrounds and were at different stages in their academic careers. Each had personal views towards STEM teaching. Participants changed their attitudes and beliefs about STEM teaching and acquired knowledge by discussing topics and completing activities in both small groups and as one community.

Methodology

Sessions during the professional development were designed by faculty members at two universities. The first day included an introduction; STEM teaching, terms such as *multidisciplinary*, *interdisciplinary*, and *transdisciplinary*, and overlaps in mathematics and science standards were discussed. Activities from the first session focused on how mathematics aids in understanding the nature of various molecular structures. Day one concluded with considering how STEM curriculum is developed. Participants were assigned groups to begin brainstorming ideas for the STEM lesson to be presented on the final day. Groups were determined in advance by the program coordinator in order to have the arrangements be as diverse as possible in terms of university attended, discipline focus, and semesters in the education program. Day two included an engineering session and a stereology session. During the engineering session participants discussed the fields of engineering and received a tour of the university's labs. The preservice teachers were able to practice the engineering design process with an activity. The stereology session was set in a biological context integrating mathematics, design, and modeling. On the third day of the professional development participants discovered how to calculate empirical and theoretical probabilities for single-gene traits without using Punnett Squares. On the last day of faculty-led sessions the preservice teachers identified macroinvertebrates, ran simulations, and used inferential statistics to investigate the water quality of a local stream. Participants received ample time to work in groups developing a STEM lesson on days three and four. The experience concluded with group presentations in which the participants shared their STEM lesson and commented on their peer collaboration.

Participants were recruited from two universities. All secondary preservice math and science teachers were sent an email detailing the program and inviting them to attend. 20 preservice teachers participated in the program, 7 males and 13 females. Participants' STEM content focus was as follows: 9 biology, 1 chemistry, 1 physics, 2 earth and space science, and 7 mathematics.

Quantitative and qualitative data were collected using two separate instruments. Quantitative data was collected using the STEM Teaching Beliefs and Attitudes (STBA) Survey. The STBA Survey was administered as a pre- and post-survey online. It contained 34 five-point Likert scale items, ranging from strongly disagree to strongly agree for measuring beliefs and attitudes towards STEM teaching. Items measured feasibility of STEM integration, value of STEM integration, and how one learns and delivers STEM content. The STBA was developed by modifying items on surveys used in similar empirical research and consulting field experts when creating new items. Berlin and White (2010) measured feasibility and value to determine preservice math and science teachers' attitudes and perceptions regarding integration. Specific elements from Lehman and McDonald's (1988) 10-item questionnaire such as "I am aware of curriculum materials designed to integrate mathematics and science" were adapted for use on the STBA Survey.

Qualitative data was obtained via blog entries. Participants were required to respond to the following prompt at the conclusion of each day: Responses may be content and/or teaching related. (a) What is something new you learned today? (b) What did you like about today? (c) What did you dislike about today? How could it be improved? (d) Would you like to learn more about the topics from today? Why or why not? Comment on at least two other posts. The preservice teachers' reflections were used for understanding the extent to which the goals were accomplished as well as informing the program coordinators what modifications should be made to the professional development.

Results and Discussion

The results from the pre- and post-STBA survey indicated increased beliefs and attitudes of STEM teaching. Wilcoxson Sign Tests were used to determine which items had statistically significant differences in the responses. Table 1 displays items with a statistically significant change in pre- and post-survey answers. The preservice teachers increased their confidence in their ability to integrate in their future classrooms. The participants responded being more likely to use STEM standards outside their discipline when teaching and more aware of integrated curriculum. Overall, after the program participants believed integrated teaching was more beneficial for students than they had previously.

There was not a statistically significant increase in the participants' intent on collaborating with other STEM teachers. This was due in part to the fact that many science teachers indicated they planned on collaborating with math teachers and vice versa, and therefore little change occurred in the responses on the post-survey. There was also little change in the participants' views on the feasibility of STEM integration.

Data collected from the participants' blog entries provided additional insight into their opinions of the program. Numerous participants commented that they enjoyed discussing with STEM preservice teachers that had different backgrounds than their own and the knowledge gained from these social interactions. "I really think that one of the valuable aspects of this workshop is that it brought a group of people together that we're at a wide variety of stages in their careers. This included participants and facilitators alike. I think that this was an important element of the workshop." "I enjoyed working with the people in the beginning of their programs and their willingness to learn and understand the process. It was great to share." "It was interesting to work not only with others from different points in their teacher preparation programs, but also from two different programs."

Table 1

STBA Survey Items with Statistically Significant (p<.05) Change

Item	p-value
Integrating engineering in secondary math classrooms is easy for the teacher.	.015
I am confident I will be able to integrate math and science in my future classroom.	.010
I am confident I will be able to integrate technology in my future classroom.	.025
I plan to make connections to STEM standards outside my content area in my future classroom.	.002
Math should be taught using an exact procedure for solving problems.	.046
Science should be taught using an exact procedure for solving problems.	.029
Technology should be taught using an exact procedure for solving problems.	.046
There are math and science lessons that integrate engineering available to teachers.	.013
There are lessons that integrate math and science available to teachers.	.005
Integrating engineering in secondary science classrooms is beneficial to the students.	.007
Integrating math in secondary science classrooms is beneficial to the students.	.011
Integrating science in secondary math classrooms is beneficial to the students.	.020
Integrating technology in secondary math classrooms is beneficial to the students.	.014
Integrating technology in secondary science classrooms is beneficial to the students.	.021

Though the data collected on the survey found no significant change in beliefs about the feasibility of STEM integration, one participant reflected on the realization of the work involved in implementing STEM teaching: "Today I realized some areas that make integrated lessons difficult. I realized how much more information you need to know to make a truly effective lesson from scratch. I think integrated lessons are highly effective in many ways, but I think they are more difficult than I first thought." Some preservice teachers mentioned being confused in the math or science portion of a session. However, they did not connect this to their future students and demonstrate understanding of the struggles they may encounter.

Participants expressed dislikes with some aspects of the TEPST program. Some thought the first two days were crammed too full. Others thought the professional learning experience was math and biology heavy. They wanted opportunities to learn more about other content areas. The majority of the participants were math or biology preservice teachers, which is why the program was designed to emphasize those fields. However, more attention should have been focused outside those disciplines. Most reflected that the final presentations were not timed well, because some groups had more time to discuss their integrated lesson than others. Even though there were a few negative aspects to the professional learning experience, overall "this was a highly productive experience."

Implications

With state and national standards calling for STEM integration it is important to train teachers for effective STEM teaching. There are few opportunities for secondary preservice teachers to taken integrative coursework, since they must specialize in one discipline. Therefore, more opportunities like the TEPST program need to be made available to preservice STEM teachers. Environments providing social collaboration allow for greater knowledge building. More professional development offerings for preservice (and inservice) secondary teachers need to have a STEM focus. As more STEM education programs are developed future research should evaluate their effectiveness.

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BUILDING PRESERVICE SCIENCE TEACHER SELF-EFFICACY THROUGH INQUIRY AND VIDEO MODELS

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Improving the science scores of elementary students will require effective teachers who have high science teaching self-efficacy. This study explored the impact of an initial and revised intervention on science teacher self-efficacy of graduate teacher education students. The interventions offered students the opportunity to explore science concepts through inquiry-based activities and to observe video teaching models using a researcher-developed protocol. Data was collected through a mixed methods approach. Quantitative findings provided mixed results as to the impact, while qualitative data show promise for developing science teacher self-efficacy and changing beliefs about instructional practices.

Introduction

Science education has become a priority in the US, and creating successful science students will require a teaching force that is knowledgeable and comfortable with science content and pedagogy. Teachers who feel inadequate about their science teaching ability may avoid teaching science topics, or not teach them well (Riggs, 1991). Unfortunately, though preservice teachers should be developing positive attitudes toward science during their career as K-12 students, many do not and thus science methods and content courses are serving a remedial function (Brigido, Borrachero, Bermejo, Mellado, 2013).

A powerful construct to consider in supporting preservice teachers is teacher self-efficacy (TSE), the degree to which a teacher believes he or she can impact student learning outcomes (Gibson & Dembo, 1984). Teachers with high levels of TSE are more likely to work with a student following an incorrect response, utilizing multiple questioning and instructional strategies (Gibson & Dembo, 1984). They tend to communicate higher expectations for their students and are able to sustain greater levels of student engagement and motivation during a lesson. The level of science TSE specifically can influence how a teacher develops science units and how much students learn (Tobin, Tippins, & Gallard, 1994), and teachers with high science TSE have been shown more likely to use innovative strategies, like inquiry-based learning (Riggs & Enochs, 1990). As a result, students of teachers with high TSE often have better learning outcomes (Ashton & Webb, 1986), including better student scores on end of year science assessments (Angle & Moseley, 2009). This may be related to the classroom environment created by teachers with high levels of TSE (Guo et al., 2012) and the fact that they are often strong science teachers (Bolshakova, Johnson, & Czerniak, 2011).

Objectives of the Study

The purpose of this mixed methods case study was to explore the impact of an original and revised intervention on the science TSE of preservice teachers. This study utilized a mixed methods approach to explore the research question: How does having graduate students engage in inquiry based activities and view video teaching models impact their science TSE?

Theoretical Framework and Related Literature

TSE is the belief a teacher holds that he or she can make a difference in student learning, regardless of whether the student is difficult or unmotivated (Guskey & Passaro, 1994). Bandura (1977, 1986, 1997) suggests that self-efficacy is contextual, meaning that teachers may have high TSE for some subjects and low TSE for others. Additionally, he proposes that self-efficacy develops based on the influence of four sources: mastery experiences, vicarious experiences, verbal feedback, and physiological responses. The development of TSE begins during teacher preparation and continues once the teacher is working in his or her own classroom (Hoy & Spero, 2005), though once TSE beliefs are established they are resistant to change (Bandura, 1997; Hoy & Spero, 2005). Elementary teachers as a group tend to have the lowest scores for science TSE (Buss, 2010).

Science TSE appears to be able to be improved through preservice coursework, but the design and focus of the course matters. Richardson and Liang (2008) found that an inquiry-based course can improve TSE, while Morrell and Caroll (2003) suggest that science methods courses can raise TSE, but content courses have a more limited impact. By contrast, Bergman and Morphew (2015) propose science content courses can have a positive influence on TSE, but they specify the course needs to be geared toward elementary preservice teachers and balance content and pedagogy. Students especially benefit from courses that blend inquiry-based activities, group work, and good teaching role models (Cakiroglu, Aydin, & Hoy, 2011). Teachers who have higher levels of personal science TSE often share they had positive preservice preparation experiences and those with lower levels the opposite (Ramey-Gassert, Shroyer, & Staver, 1996). Additionally, higher personal science TSE correlates with a more positive attitude about science and choosing to teach science.

Methodology

The participants in this study were graduate students enrolled in a one-semester course that covered math, science, and technology methods at a small, private college in the northeast. This course was required for the students who were pursuing early childhood or elementary teaching degrees, most choosing a dual degree in special education. In Phase 1 there were 11 female students, and in Phase 2, 13 female and 1 male student. Phase 1 was completed in the fall of 2012, and Phase 2 in the spring of 2014.

In Phase 1 the intervention consisted of two parts carried out in each class that were based on the science topics that aligned with the textbook chapters for that week. The first part was an inquiry based content review at about the fourth grade level. The second part was the viewing of video models while filling out a video protocol form. The videos came from a number of websites, with the majority from www.teachingchannel.org. Before the video the protocol asked students to record ideas for teaching the topic and indicate their level of confidence for teaching the topic using a 5-point Likert scale. During the video the students recorded more ideas for teaching. Following the video they discussed their ideas with a partner, added any additional teaching ideas, and again indicated their level of confidence. These activities were designed to provide mastery and vicarious experiences which have been shown to influence TSE (Bandura, 1977).

In Phase 2 the intervention changed in several ways. First, the course was realigned to correspond to the State Elementary Science Core Curriculum (SESCC) process skills and standards. Thus, the course textbook was replaced with the SESCC documents available on the state website and other articles as selected by the instructor. Additionally, the inquiry based activities and video models were aligned to the SESCC, and the activities focused on a wider range of grade levels and were all completed as small groups. The goal of the revised intervention was to continue to provide mastery and vicarious experiences but also to provide verbal feedback through group interactions, another influence on TSE.

To answer the research question quantitative data were collected using the Science Teaching Efficacy Beliefs Instrument (Riggs & Enoch, 1991), and qualitative data were gathered through open-ended questions from the post administration of the STEBI, video response protocol sheets, and additional course artifacts. The STEBI (Riggs & Enoch, 1991) consists of 25 items using a 5-point Likert scale that factor into two subscales. The first subscale measures Personal Science Teaching Efficacy Beliefs (PSTEB) which indicates the teacher's belief that he or she can personally impact student learning in science. The second subscale indicates Science Teaching Outcome Efficacy (STOE) which demonstrates the teacher's belief that teachers in general can influence student outcomes in science. Students were asked to complete the STEBI at the beginning and end of the five to six week science section of the course.

On the post administration of the STEBI students were given four additional open-ended questions to answer. These questions asked students to reflect on if and how their TSE for science changed, which activities and class materials influenced any changes, and what they needed to do to continue building their TSE. The questions, along with the scored surveys, were given back to students during the final class and used to initiate a class discussion on the impact of the course. Additionally, all student work including the video protocols and exit passes were included in the qualitative analysis.

Analysis of quantitative data collected from the pre- and post-administrations of the STEBI were analyzed using two-tailed paired t-tests for the overall scores and the PSTEB and STOE subscales. All qualitative data were first read to gain an overall sense of the students' perspectives. Then the data were coded first using a deductive process to determine the impact of the intervention components and second using an inductive approach to allow other codes to emerge (Miles, Huberman, & Saldana, 2014). Codes were then categorized and grouped together by similarity (Ary, et al., 2006). This allowed overarching themes to surface.

Results and Discussion

Phase 1 Results

The analysis of STEBI scores was based upon 9 pairs of matching pre- and post-administration scores. Results from the two-tailed, paired t-test indicated no statistically significant increase ($p < .05$) on the overall STEBI, or on the PTSEB or STOE subscales. In fact, scores on the STOE subscale decreased, but the decline in scores was not statistically significant. Means and analyses are presented in Table 1.

Table 1.
*Phase 1 Comparison of Pre- and Post-Test Scores on the STEBI**

Scale	Pre-Test Mean	Post-Test Mean	Difference	p value
STEBI	91.7	98.1	6.4	0.1837
PSTEB	50.0	54.2	4.2	0.1176
STOE	43.8	40.3	-3.4	0.0961

*n = 9

Qualitative data, however, indicated a positive impact of the interventions on TSE for science based on four themes: general comments, hands-on activities, video viewing, and other class assignments. Students generally indicated an increase in their TSE for science. For example, Nora (survey response, December 17, 2012) shared, “I think that the course has changed my confidence because it has given me new ways and ideas to teach science.” Lily (survey response, December 17, 2012) stated, “I never knew how comfortable I would feel teaching [science]. I’ve definitely gained more confidence.”

The students also referenced the intervention components’ impact on their TSE for science. For many students the hands-on experiences were viewed as most important. “[My confidence for teaching science] has changed because I know how to select science experiments that kids can relate to and that catch their attention. I also select experiments that are hands-on and that I know about,” shared Zoe (survey response, December 17, 2012). Hannah (survey response, December 17, 2012) expressed the value of the hands-on activities, remarking that her confidence increased by “using the hands-on approach. Before I would only use the textbook because that’s the way I was taught.” Sarah (survey response, December 17, 2012) made the connection between doing the hands-on experiments herself and the way in which it might impact her future students. She explained that her confidence for teaching science increased in part because “I have also done a lot of thinking about ways in which students can construct their own understanding of science topics through investigation.”

The video portion of the science intervention was mentioned far less than it was for the math intervention. Kelly (exit pass, December 10, 2012) briefly mentioned the videos, saying “I enjoyed the lectures, the hands-on experiments, and the movies.” Lily (survey response, December 17, 2012) gave the videos more praise, sharing that “the videos shown in class were also good tools to get us thinking about our lessons.” She also indicated that she would “love to access more of the videos online” once the course was completed. The only other mention of the videos was in reference to one specific video shown on how to teach a cross-curricular unit on hurricanes, which many students said they enjoyed.

Students referenced other course components as helping them increase their efficacy for teaching science. Sarah (survey response, December 17, 2012) commented on the science field work assignment saying, “[My confidence for teaching science] has changed because first of all I have had an opportunity to teach science.” Other students echoed this sentiment with statements such as “[the science lesson plan] allows future educators to practice and experiment in the classroom,” (Zoe, survey response, December 17, 2012) and “ provides the hands-on experience needed to both teach and learn science. Also it is good to practice to learn what could have been done differently," (Colleen, survey response, December 17, 2012).

Phase 2 Results

The comparison of scores on the STEBI for Phase 2 included 9 pairs of matching pre- and post-test scores. Results from the two-tailed, paired t-test indicated a statistically significant increase ($p < .05$) in scores on the overall STEBI, but no statistically significant increase on the PTSEB or STOE subscales. Means and analyses are presented in Table 2.

Table 2.

*Phase 2 Comparison of Pre- and Post-Test Scores on the STEBI**

Scale	Pre-Test Mean	Post-Test Mean	Difference	p value
STEBI	90.8	97.6	6.8	**0.0058
PSTEB	47.6	51.2	3.7	0.0276
STOE	43.2	46.3	3.1	0.0431

*n = 9 **p value is significant at the .05 level (2-tailed)

As in Phase 1 qualitative data explained how the students' TSE for science improved during the course and focused on three themes: general comments, inquiry-based instruction, and hands-on activities. Alicia (survey response, May 19, 2014) wrote, "I feel more confident in the fact that I can teach science and actually explain what is going on behind the surface." Sheila (survey response, May 19, 2014) shared, "I was confident in my ability to teach science, but now I have a better understanding of how to teach it more effectively," indicating that the intervention may be able to improve TSE for students with both high and low initial scores.

Another theme that emerged reflected an increase in TSE specifically for inquiry-based science instruction. "I feel that I will let my students generate questions and predictions more before the lesson is taught and then lead them through self-discovery learning to test their predictions," explained Jean (survey response, May 19, 2014). Mark (survey response, May 19, 2014) described a change in thinking by stating, "I was not as confident in having students actively engage in science lessons as a method of instruction. I have seen many examples that show this method may be more effective than the concrete/lecture method I grew up under."

Student responses also expressed the influence of the hands-on experiments, one of the interventions, for building their TSE. Alicia (survey response, May 19, 2014) listed several experiments and described them as "engaging and meaningful," and Carrie (exit pass, May 19, 2014) shared that "they were very helpful and inspiring for me." Several students were particularly inspired by an activity in which groups of students were given several different kinds of pre-packaged chocolate chip cookies and asked to devise a way to score the cookies and determine the best one. Mark (survey response, May 19, 2014) explained that this experiment was influential “because we learned how much more effective it is in promoting students being active learners over following a set design. [It was] student-centered.” Finally, Melissa (exit pass, May 19, 2014) summed up her course experience saying,

> I am not a math and science person, but the thing I learned most that was invaluable was that you don’t have to be to make it exciting and interesting for kids. The more kids are involved and own their learning, the better off they will be for it.

Implications

The findings from this study provide some insight into the needs of preservice elementary and early childhood teachers who will be teaching science. Student responses indicate that using an inquiry-based program changes their understanding of how to teach science, moving them toward using hands-on activities and away from textbooks and lectures. Including the inquiry-based activities and video role models in the science methods course may offer preservice teachers the kind of course experiences they need to build their TSE and provide better learning environments and outcomes for their students.

While the video portion of the intervention was directly mentioned only by students in Phase 1, data indicate the students in Phase 2 were very focused on the hands-on activities and on how strong an influence those activities were for them. Perhaps the videos did not receive mention because the experimental method of doing science was such a departure from how they perceived science would be taught prior to taking the course. Additionally, Star, Lynch, and Perova (2011) suggest preservice teachers need to be explicitly taught to “notice” the significant features of a lesson while viewing lesson videos. In this study intervention the video response sheets were provided to help students narrow their focus, but noticing skills were not expressly addressed.

While this study showed some promise for improving science TSE, there were a number of limitations that suggest further study is needed to support results. For one, the number of participants in each phase was small, was not controlled between courses, and the relation between their backgrounds was not explored. Also, this study looked at the overall impact of the intervention, rather than focusing on the influence of the individual components or the interaction between them.

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A CULTURALLY RELEVANT APPROACH TO EQUITY INSIDE A VIRTUAL SIMULATION MATHEMATICS CLASSROOM

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Pre-service teachers at a university in the south were enrolled in a mathematics problem-solving course where they were taught the fundamentals of culturally relevant pedagogy (CRP). The 21 teachers in this study created a lesson plan that we scored based on the Rubric for Incorporating Cultural Relevance (RICR). We found that many of these pre-service teachers did not succeed in fully incorporating CRP tenets into their lessons. The pre-service teacher with the highest score received 21 out of 33 possible points; the pre-service teacher with the lowest score received 12 points where there was a lower bound of 11.

Introduction

Pre-service teachers have an obligation to learn the teaching craft in such a way as to promote equity among all students in their classrooms, and the challenge to communicate this obligation to pre-service teachers is an effort that must be taken on by all teacher preparation programs. Equity for all is only possible when teachers begin planning intentionally from a frame of cultural competence and when they promote consciousness of inequity that exists in current school structures. For this reason, the Knowledge for Algebra Teaching for Equity (KATE) Project is devoted to training its pre-service teachers in culturally responsive teaching methods that will be employed in their mathematics problem-solving lessons. We contend that many pre-service teachers enter the classroom unaware that inequities exist and that they tend to be confident in their ability to teach students who come from diverse backgrounds (Davis et al., 2015). The research conducted as a part of this grant continues to combat these notions of equity through its preparation of mathematics teachers as they acquire pedagogical knowledge that pertains to two crucial elements of teaching: mathematics knowledge (Kulm, 2008) and equity consciousness (Davis et al., 2015). We believe that the true artisan learns to teach in the intersection of the two constructs, and KATE will continue with this initiative.

Objectives of the Study

The goal of the present study is to analyze how well the pre-service teachers are incorporating culturally relevant teaching strategies into their lesson plans. Culturally relevant pedagogy (CRP) is a pedagogy that caters to the needs of all students that are in the classroom; it capitalizes on the theme of equity. Our goal is to find the trends in the pre-service teachers' lessons that emphasize CRP in an effective manner and to correct the misconceptions that teachers have in attempting to use CRP. This purpose captures how well teacher educators are communicating the role and definition of teaching for equity to pre-service teachers, and it identifies those areas where we need to assist future educators in developing a greater pedagogical understanding. Furthermore, the objective of our study is to critique and measure the level of cultural relevance within each plan. Though we agree that many culturally relevant aspects may arise in the delivery of the content, teachers must plan to use CRP and make its effects conspicuous even prior to the lesson. Therefore, the pre-service teachers, knowing that their lesson plan was being graded according to the scheme, should have overemphasized aspects of CRP in the lesson plan. We used the data presented in this research to answer two questions:

1. How well and to what extent did the lesson plans created by the pre-service teachers reflect a culturally relevant pedagogy?, and
2. What evidence supports or nullifies their labeling of the lesson as culturally relevant?

Theoretical Framework

Renewed and consistent attention on the need for equity in the classroom is an issue that has been debated for years (e.g. Du Bois, 1935; Gay, 2010; King, 1991). Du Bois asserted in his seminal work that it is necessary for teachers to know the background and surroundings of the students they teach; acquiring this knowledge about students will make a difference in pedagogy. It will also aid teachers in acknowledging that there is no deficiency with their minority students, and that reality may more often times reveal that deficiency lies in the schools and in the teacher (Milner, 2006). Education has not evolved much since the time that Du Bois (1935) predicted that if public schools opened their doors to all students, those of color would receive the most pitiable of all instruction.

Equity concerns have found a place within mathematics education among various levels of the curriculum. Ortiz (2014) noted that students of color routinely experience mathematics classrooms that are dominated by moot forms of instruction such as remediation, memorization, and drill, especially in an atmosphere where high stakes testing is so prevalent (Lattimore, 2003). This form of "teaching" requires little knowledge about how students learn mathematics and it lacks the cognitive demand that prepares students for more advanced mathematics. Berry and Walkowiak (2012) communicated agreement with this notion in their description of poor instructional quality for African American students. They suggested that no true mathematical meaning happens in teaching environments devoid of such constructs as problem solving, explanation and justification, and mathematical discourse. Further discussion can center on the realization that students of color have less frequent access to advanced mathematics classes, specifically in their enrollment in middle school algebra (Spielhagen, 2011). Equity issues are prevalent in middle school mathematics classrooms considering that these advanced level classes are disproportionately non-African American.

We posit that the disconnect within mathematics education is the same one that is seen in general educational matters, specifically in the instruction that many students of color are receiving. They should have opportunities to learn in ways that value their culture and reify the backgrounds from which they come. Further, we content that this goal must be met even in the mathematics classroom; it is a task that belongs first and foremost to the mathematics teacher.

Equity is a right that all students deserve, and it can be mastered through what Ladson-Billings (1994, 1995, 2006) has defined as a culturally relevant pedagogy. This framework that was used to guide our study rests upon three tenets: (a) students must experience academic success, (b) students must develop and/or maintain cultural competence, and (c)students must develop a critical consciousness through which they challenge the status quo of the current social order (1995, p. 160).

Incorporation of a pedagogy that encourages academic success and achievement values the knowledge and experiences of the students in the mathematics classroom. It is the result of students' interactions with a teacher that is well-versed in what Shulman (1987) has termed as a content knowledge base for teaching. Cultural competence refers to valuing the student's culture and allowing this culture to exist within the classroom. This means that students are free to remain true to the backgrounds and ideas that they possess as it relates to their life outside of school. Lastly, sociopolitical consciousness is comprised of students' realizations that the society they live in always has room for improvement. Mathematics should initiate the plans that students develop in the quest for a better life for each other and their communities.

Methodology

There were a total of 21 pre-service teachers who participated in a spring semester mathematics problem-solving course in 2014, and this data is a reflection on their abilities to create lesson plans that honored the tenets of culturally relevant pedagogy. These pre-service teachers chose one of three various conceptual schemes to create a lesson: a) situated learning, b) cultural relevance, or c) critical pedagogy. They all chose to develop lessons that were grounded in culturally relevant pedagogy as they led students through solving a word problem in a virtual classroom. The course professor assigned the pre-service teachers a reading of Ladson-Billing's (2006) "Yes, But How Do We do It? Practicing Culturally Relevant Teaching" to help them develop an idea of the tenets involved in CRP and provide lesson examples. The article exposed them to the three tenets that have shaped culturally relevant pedagogy since its creation and offered insight into what these themes look like within a classroom.

We assert that teachers who stipulated that they followed a culturally relevant scheme should demonstrate evidence of culturally relevant pedagogy in their lesson plans, and that these constructs are not solely based in the delivery of the lesson. Anecdotes of academic success, cultural competence, and sociopolitical consciousness can be seen when teachers plan their lessons, especially when pre-service teachers are required to develop a lesson that is reflective of culturally relevant pedagogy. We advanced our research efforts by using Ladson-Billing's descriptions of the three tenets to create the Rubric for Incorporating Cultural Relevance (RICR), a rubric that included 11 indicators used to grade each pre-service teacher's lesson plan. These indicators were subcomponents of the 3 tenets aforementioned, and they were developed in response to the examples and clarification provided in Ladson-Billings (1994) work. The indicators are the interpretations of what she conveyed in each meaning, and they aid in delineating each strand as well as each indicator. Pre-service teachers could achieve a 1, 2, or 3 on any given indicator where 1 identified that the pre-service teacher made no attempt to incorporate the indicator, 2 indicated that the pre-service teacher made a partial attempt to incorporate the indicator, and a 3 indicated that the indicator was fully addressed. The rubric was created with a section for comments and justification, and each indicator listed possible sources of evidence.

The RICR used four indicators to expand upon academic success (AS), four indicators to expand upon cultural competence (CC), and three indicators to expand upon sociopolitical consciousness (SC). Teachers who promote academic success in the classroom a) draw on issues that are meaningful to the student, b) indicate a purpose for students learning the content and makes students aware, c) utilize the students' skills and prior knowledge, and d) supplement learning by using resources in addition to a textbook or the word problem. Teachers who promote cultural competence a) use cultural artifacts as learning tools, b) emphasize the role of family as a knowledgeable source, c) expose students to the dominant culture with a purpose of critiquing it, and d) allow recognition of the students' culture and embraces it. Lastly, teachers who promote sociopolitical consciousness a) encourage students to engage in the world critically to better understand their social position, b) highlight alternative perspectives or approaches to problems, and c) help students develop ways in which to community problem solve.

Evidence that supported a particular indicator could be found in various parts of the lesson plan including the mathematical concepts or procedures, the rationale for the context selected, statement of the problem, the solution and its alternative, probing questions, extensions, or the actual PowerPoint pre-service teachers would be using in the virtual classroom; all items were a requirement.

Results and Discussion

Pre-service teachers who were never exposed to any elements of culturally relevant pedagogy would have at minimum a sum of 11 for all eleven indicators. Conversely, a teacher with a score of 33 would be deemed as a model CRP teacher and have scored a three on each indicator. In reality, each pre-service teacher falls somewhere within these two extremes due to his or her attempt to incorporate at least one of the indicators and their failure to meet them all. Additionally, most effective teachers should accumulate points on some of these indicators such as those listed under academic success, because these are basic steps of good teaching. The results discussed herein identify themes, exceptions, and overlaps within our data.

First, we noticed that there were only four indicators that were fully incorporated by a pre-service teacher. These four indicators included: AS2, AS3, CC4, and SC2; AS3 had the most pre-service teachers to fully incorporate a single predictor, and this accounted for three out of the 21 pre-service teachers. AS3 corresponds to the academic success strand and more specifically is the indicator that looks for the pre-service teacher to utilize the prerequisite knowledge of the students. We determined that this evidence could be found in the "devising the plan" or the "looking back" portion of the lesson plan. For example, one pre-service teacher named Corri (a pseudonym) demonstrated this by asking students to define the purpose of the percent sign in their problem. A culturally relevant teacher believes students possess this knowledge and tries to elicit memories of prior accounts with the mathematics. We also found that Patricia accounted for various interpretations of drawing a cake because she knew some students would assume it was round and others would assume it was a square. The idea is that students have this knowledge of drawing a figure to represent fractional parts and the teacher recognizes that she will have an opportunity to build on what they already know.

The results suggested that AS4, the indicator declaring the teacher uses additional resources other than the textbook or problem, was either the most difficult for pre-service teachers to incorporate in a written document or the most difficult to find evidence for in the lesson plan. No teacher in the current study got a score on this indicator other than a one because teachers would have had to explicitly state the source from which they were pulling this supplemental material. Furthermore, we extended this requirement to elaborate on indicator CC1 where pre-service teachers could have used a cultural artifact as this supplemental material. We looked for an item or entity that could be operated on mathematically and used to draw mathematical conclusions; for CC1 this item had to be something that students were familiar with inside of their cultures. We felt Patricia made an effort to oblige this requirement because she validated a cake as being an item that was familiar to many of her students, and it was one that students who had been exposed to circular, rectangular, even triangular shaped cakes could use to comprehend the mathematics. We contend that elements of one's culture and background would determine the cakes that they have seen and the venues in which they have come into contact with one. Other examples for this cultural artifact could have been a receipt that students used to find tip totals or an advertisement displaying items being sold at discounted prices. Given the similarity of these two indicators, we expected results to be fairly close. Only Patricia and Peter achieved a score other than one on this indicator, and it was partially incorporated in both cases.

A rank order for the bottom and top three indicators of performance confirms some of our initial notions. In addition to AS4 being the least incorporated indicator, SC3, CC1, and CC2 had respectively 95.2%, 90.5%, and 71.4% of pre-service teachers who did not incorporate the indicator. The cultural and sociopolitical conscious aspects of culturally relevant pedagogy seem to be the most difficult aspects to incorporate. They are the components that are critical to this pedagogy and teachers must intentionally plan to use them if they want students to feel that their culture is reflected in the learning process. Many of the pre-service teachers operated with a mentality like that of Faye who suggested that because her problem involved a situation that could actually happen, it was culturally relevant. She described a problem where students used unknown information about classmates' heights to represent other heights as algebraic expressions. This problem lacks any relevance to a student's culture and it seems that quite a few of the pre-service teachers in this study acquired this misconception. They totally neglected other tenets of CRP and often times mentioned a food, item, or situation that could happen in any country or any child's life at any given moment, as something unique to their culture. Furthermore, a sociopolitical conscious approach to mathematics would require teachers to have their students critique the world and their position in it, as well as foster instances of community problem solving. Only Gladys came close to meeting this requirement because she defended the need for her students to share the candy that was the subject of her problem. She used the rationale section to advocate for students' questioning of whether they needed this characteristic and to what extent; they realized that candy should not be reserved solely for themselves. The indicators with the highest percentages of incorporation were SC2, AS1, and CC3 with 9.5%, 9.5%, and 14.3% respectively (these percentages represent presence of a 1 on that indicator). These indicators were not as hard to commit to because they are easily accessible with most mathematics problems. Pre-service teachers got many 2s in exposing students to the dominant culture, but the difference between partial and full incorporation was exposing the students to this culture with a purpose for critiquing it. Mathematics teachers often times have an alternative approach to solving math problems, and this was perhaps an indicator that CRP teachers will not have much trouble incorporating; they must still work on allowing discussion surrounding which perspectives or approaches are better than others, a task that Gladys provoked in her probing questions.

A final point worth mentioning about these indicators is that pre-service teachers often gave a rationale for the problem they were using, but did not specifically discuss the mathematics (AS2). They would give explanations like Georgia who said the cafeteria setting would be familiar to her students, but did not communicate why they needed to learn the expressions that were taught in the lesson. Furthermore, some pre-service teachers mentioned the rationale on their lesson plan but did not communicate mathematical purposes to their students. We looked for teachers like Corri to share this information in the introduction of the problem, but 66.7% of them did not attempt to incorporate the indicator.

The range of scores in this study was from 12 (Faye) to 22 (Gladys). A score of 12 does not contest Faye's knowledge of CRP, but it does suggest that she is not as efficient at incorporating it into a written mathematics lesson. Similar conclusions can be drawn about some of the other pre-service teachers.

Implications

Culturally relevant teaching is critically important in teaching for equity in today's mathematics classroom. Our results show that although teachers may have intentions of validating the culture of their students, even after declaring that they have prepared a culturally relevant lesson, they can fall short of the ideals that actually help students develop and affirm their culture. Within this program we recognize the need to expose the pre-service teachers to more theory about culturally relevant pedagogy, and we have the resources to share this information with students in the problem-solving course. Completion of this investigation has demonstrated a need to discuss the aspects that are often forgotten in designing a culturally relevant lesson plan. Additional examples of sociopolitical consciousness and cultural competence need to be utilized in the course, and pre-service teachers should be given explanations and tips for describing lesson delivery. Future research should take into account these suggested course improvements and compare lesson plans across semesters.

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DEVELOPING STEM EDUCATORS THROUGH PROJECT-BASED INSTRUCTION

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Innovative professional development strategies are needed to equip secondary mathematics and science teachers with the knowledge and skills to prepare students for STEM careers in equitable ways. This paper reports on the development, implementation, and initial findings of the STEM Center, a collaborative professional development program that centers on culturally responsive, project-based teaching strategies. We will discuss the ways in which we structured the program based on current literature and present findings related to the ways in which the STEM Center has affected teacher beliefs, practice, and outcomes.

Introduction

There is high demand for individuals who are able to critically think through problems that are prevalent in science, technology, engineering, and mathematics (STEM) fields and industries. Additionally, there is concern around the pervasive gaps in access to higher-level mathematics and science content between traditionally underserved students and their counterparts (Flores, 2007; Lee, 2002). Further, there is a need to encourage greater participation of women in STEM related careers. Teachers are in a unique position to prepare students from all backgrounds for work in STEM fields by developing a unique and comprehensive set of problem solving skills through innovative mathematics and science instruction. In an effort to address these needs locally, and encourage these types of pedagogy, faculty and staff from the College of Engineering, the College of Education and Human Development, the College of Sciences, and the Academy for Teacher Excellence at the University of Texas at San Antonio partnered with local high-need school districts to develop the STEM Center. A collaborative effort, the STEM Center provides professional development using a STEM-focused, culturally responsive Project-Based Learning (PBL) approach in order to help secondary mathematics and science teachers in high-need schools implement innovative, project-based practices in their classrooms.

The overarching goal of the STEM Center is to improve student achievement in STEM subjects in high-need schools, so that these students may graduate with increased access to a greater pool of options in terms of higher education and employment. The STEM Center seeks to accomplish this through teacher development and partnerships that set the stage for South Texas school districts to become more STEM-focused while infusing the curriculum with developmentally appropriate PBL activities that are correlated with the Texas Essential Knowledge and Skills and College and Career Readiness Standards.

Teachers involved with the STEM Center were recruited in two groups. Year one, the Alpha group, which consisted of 21 teachers, began the project, attending a two week summer institute and monthly Saturday sessions during the academic year. From a first year teacher, to a veteran of 35 years, this group had a mean of 10 years of experience teaching high school mathematics. Year two, 29 members of the Beta group joined the Alpha group, largely coming from campuses where at least one teacher was already a part of the STEM Center. This second group had a mean of 5.3 years of experience teaching high school mathematics. This team approach allowed for collegial collaborations, support at the campus level, and more impactful implementations. During STEM Center sessions, teachers engaged with faculty from Engineering, Mathematics, and Mathematics Education in PBL activities, reflected on their experiences, and planned for implementations. Participants also received mentoring at the classroom and campus level related to project implementation. Moreover, teachers have presented findings related to these implementations at professional development sessions and local or state conferences.

Objectives of the Study

The goal of this study was to determine the effectiveness of the STEM Center in particular areas of participant practice and, ultimately, in terms of student outcomes. In order to determine the ways in which the STEM Center has affected teacher practice, we have collected a variety of data while engaging in an ongoing process of planning, data collection, and data analysis related to the following research questions:

1. How does a PBL approach influence change in science and mathematics teachers' attitudes, beliefs, and practice?
2. What are the challenges that teachers experience as they reconcile their existing orientations towards teaching and the tenets of PBL?

Related Literature

Project-based learning is a student-centered approach that involves experiential student learning through work on projects (Bell, 2010). While “real-world” problems and applications may be included in daily instruction, most of these activities are fundamentally different from PBL. During PBL instruction, content is delivered through a project, which is focused on a driving question that connects the content and the student activities (Blumenfeld et al., 1991). PBL is inquiry-based, whereby students acquire new knowledge or understanding through the activities and provides students with a significant degree of autonomy throughout the experience (Bell, 2010). Moreover, PBL projects are authentic, and present real-world scenarios and problems for students to solve (Gordon, 1998).

PBL has been studied in K-12 classrooms with promising results in terms of student outcomes in high-need schools. PBL has been shown to contribute to significant gains on standardized test scores in mathematics and science (Boaler, 1999; Geier et al., 2008), particularly among economically disadvantaged students of color (Geier et al., 2008). This finding was especially significant, as African American boys showed highly significant growth not only in academics, but also socially. As a result, dropout rates decreased. Students participating in PBL programs have also been shown to achieve higher scores in the applied and conceptual problem subsets than their counterparts who engaged with traditional curricula (Boaler, 1999). In addition to gains in test scores, several studies indicate significant improvement of problem-solving skills (Gallagher, 1992), communication, collaboration, and attitude towards learning (Bell, 2010). The effectiveness of PBL in the case of English Language Learners has also been documented (Beckett, 2002).

Methodology

The study presented here aligns with the constructivist qualitative tradition which seeks to explore the ways in which participants experience and construct meaning of some phenomenon in their own worldly context (Cresswell, 2014; Guba & Lincoln, 1994). Given the dearth of literature on the impacts of PBL engagement on teacher practice, we collected and analyzed data from different aspects of the project. These data included surveys given at key points in the program, teacher journals, classroom observations, teacher products, small and large group discussions (video and audio taped), and teacher reported student data. Data analyses included quantitative and qualitative approaches. Survey data were analyzed using factor analysis, and qualitative data were collected and analyzed using a combination of phenomenological and narrative analyses. Phenomenologically, our goal was to externalize participants' internal sense making and subjective interpretations of experiences related to the project (Mertens, 2005). For example, we wanted teachers to describe their experiences in the program, and how those experiences may have impacted their own classroom practice, from their perspectives. Within this framework, teacher narratives were interpreted to holistically examine the phenomena (Daiute & Lightfoot, 2004).

Results and Discussion

At this time, teachers are still involved in the final stages of the project, and continue to implement PBL in their classrooms. As such, data analysis is ongoing; however, some preliminary analyses of the bulk of the data have yielded some important initial results related to teacher beliefs, practice, and student outcome results. Generally, at the end of the project, teachers believe more strongly that PBL increases the chances of success in mathematics and science for a broader group of students. More specifically, through journals and large group debrief sessions, teachers identified many benefits of PBL (see figure 1). Among these, student engagement was reported the most often. This is a significant finding, as teachers indicated low student engagement in mathematics and science at the beginning of the project. In all areas of data collection, teachers reported "genuine engagement [in PBL tasks], synthesizing of information, and retention" and that students were "making connections between content and project…instead of just parroting isolated content". Moreover, our data show that traditionally underserved students, in particular, are more likely to participate and achieve at higher levels in mathematics and science when a PBL approach is utilized, as opposed to a traditional lecture. As expressed through illustrative quotes from teachers' surveys, many teachers reported that traditionally underperforming students "become the leaders in class [because]…some typically higher level students or GT students are afraid of making mistakes and have trouble with not having the right answer" while "special ed [sic] students are able to make connections that they aren't always asked to make" in traditional step-by-step instruction. For these reasons, 81% of teachers recommended increasing class time devoted to PBL.

Also shown in figure 1 are drawbacks of PBL as reported by participants. Ultimately, these drawbacks highlight the feeling among teachers that PBL and standardized test preparation do not complement one another. Though teachers believe students are gaining relevant skills related to the standards through PBL, they feel that they must still spend additional time on test preparation in a non-PBL setting. Over half of our participants believe, however, that students will perform better on standardized tests in mathematics and science partly as a result of PBL.

Most participants reported that they believe that PBL is a more effective instructional strategy than traditional instruction; however, the challenges mentioned in figure 1 preclude implementation of a true PBL curriculum. Most notably, the struggle between innovation and standardized test preparation has caused cognitive dissonance for participants. This highlights the struggle that teachers feel when a curriculum that is focused on student learning does not align with a curriculum that helps students prepare for standardized tests. For example, a teacher who spent three days on PBL and two weeks preparing for the test in a traditional manner (using district-mandated materials) felt that “students learned more and were more creative in the three days of PBL than during the two weeks [of test preparation].” This pedagogical approach (separating PBL from traditional content instruction), however, indicates that participants view PBL as an add-on to the traditional curriculum rather than a theoretically different, holistic approach to math and science education.

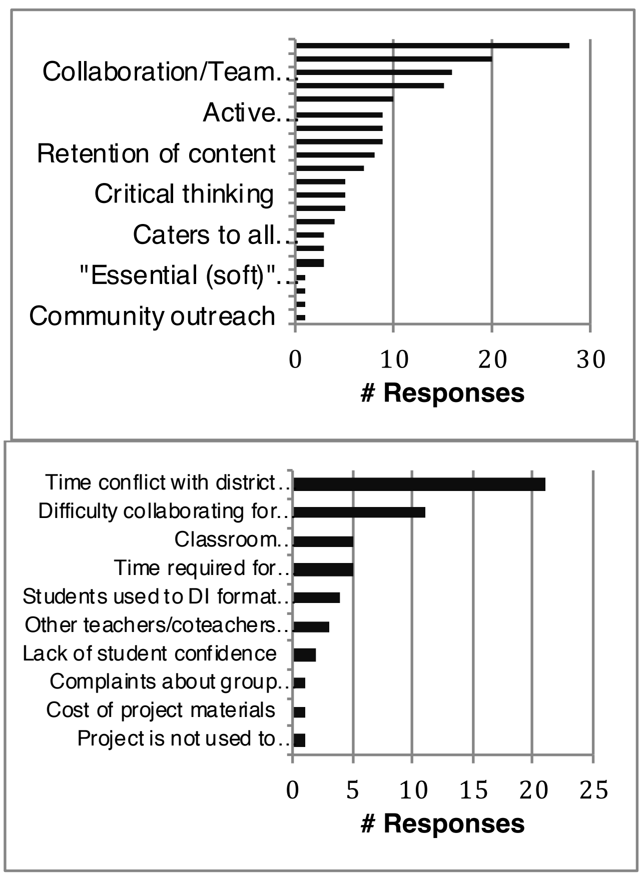

Figure 1. Benefits and Drawbacks of PBL as reported by participants.

This finding implies that over the two-year project, participants may not be fluent enough in PBL to deviate from the standardized curriculum. More specifically, we observed many teachers implementing complex activities that were not connected to a project, instead of true PBL. Though this did indicate a more surface level understanding of PBL, we did see movement among these teachers towards more open-ended problems, and we did see many tenets of PBL reflected in their teaching. Teachers also reported feeling pressure from administrators, parents, and the system at large to implement the traditional curriculum with fidelity, even though it had not increased student achievement or engagement over time. In schools where little support was provided for PBL implementation, participants felt isolated and more challenged by limitations such as time than their peers who worked at campuses where opportunities to collaborate and support were available.

The majority of teachers reported observing greater benefits in student academic success in areas that are not necessarily measured by tests. For example, teachers observed PBL having a positive influence in students interest in mathematics by being able to solve real-world problems, increasing their skills for collaborative learning, reducing students' math anxiety by "connecting the mental and physical", and academically benefiting a diverse group of student population simultaneously, including gifted and talented, English Language Learners, and Special Education. Similarly, the research team saw significant shifts in pedagogical practice related to the tenets of PBL, which permeated practice not only during project implementations, but also during traditional instruction. For example, we observed a greater amount of collaboration and student justification overall (not just during projects) in classrooms where teachers had implemented PBL. Further, though many teachers struggled to move past contextual activities into true PBL, we did observe movement toward a PBL approach.

Implications

There are many important implications of this work for teachers, teacher educators, policy makers, administrators, and other stakeholders. Most significantly, our findings indicate that implementing PBL to any degree increases access to higher-order thinking in mathematics and science for students who typically do not engage with traditional mathematics or science. This implies that PBL can be used to promote equity at the curricular level. Further, our classroom observations corroborate teacher reflections that PBL requires students to think critically about situational and applied mathematics, while traditional instruction requires mostly rote memorization and learning knowledge generated elsewhere. In PBL, mathematical ideas emerge from the discussion and are generated by the students themselves. This leads to empowerment and confidence, greater retention of material, and more connections between traditionally disparate content areas. As such, PBL shows great promise as a pedagogical tool, and as a driver of the curriculum. Our findings support the use of PBL in high-need schools.

Administrators and curriculum specialists at the district level should consider these findings in writing curriculum. Many of the teachers in the study report some version of the sentiment that “direct instruction is boring to most students, and most of the time they zone out after five minutes”. PBL gives students a hands-on activity that is thought provoking and requires higher-order thinking skills, yet students are engaged, motivated, and competitive with one another. Further, teachers report that students learn perseverance in problem solving, and are actually learning similar skills that will “help them in the long run” not only in higher-level mathematics courses, but also in the workforce. Moreover, teachers reported that students gained “other” skills that are typically not built through traditional instruction, such as improved ability to communicate orally and in writing (mathematically and otherwise), justify solutions and make productive arguments, and connect ideas in a logical manner. These skills are not only foundational to higher-level mathematics, but are also useful in all areas of life. From a curricular standpoint, these findings imply that mathematics and science education needs to shift to project-based lessons, and away from more traditional direct instruction.

While there are many benefits to PBL, there are also some issues that we encountered that are important to mention, as they are relevant to teachers and teacher educators. Our data show that a large percentage of our teachers, many of whom had a full two years of professional development around PBL, were implementing activities rather than true projects, as defined by PBL. For example, one group of teachers implemented an activity based on the popular game Angry Birds, wherein students are asked to build quadratic equations from partial information. While the activity did encompass many tenets of PBL (real-world problem, building something within a set of parameters, addresses process standards such as communication), it is clearly not a “project.”

There are several ways to interpret this finding. First, this type of activity building could be a result of teachers seeing many of the benefits that PBL brings to their students, and thus, they are developing activities that, although not truly project-based, do move away from direct instruction and traditional textbook materials. This interpretation is supported by our data, which show that teachers felt challenges related to PBL implementation, such as time and curriculum. For example, on some occasions it was difficult for teachers to align a project with the curriculum (specifically related to the State of Texas Assessment of Academic Readiness test). Thus, although teachers perceive challenges with PBL, many teachers became more creative in designing and adapting non-PBL activities that move away from direct instruction and traditional textbook materials in an effort to access the many benefits of PBL.

Second, although we did see value in these sorts of activities as (a) students were more engaged than with traditional direct instruction and (b) it did show innovation and movement towards project-based lessons, these types of activities could suggest a surface-level understanding of PBL on the part of the teachers. This is somewhat supported by other data sources wherein teachers seem to view PBL as an extra pedagogical tool rather than a foundational framework for instruction. This is important to note for teacher educators, as teacher learning and implementation around PBL is an ongoing process that takes a great deal of time, particularly given teachers' curricular and time constraints. This is further complicated by the omnipresent standardized test, as discussed above.

Given these initial findings, we believe that more longitudinal studies are needed to determine the effectiveness of PBL in a wider variety of classrooms and settings. Further, more student achievement data should be included in these analyses. It is important to note that many of our participants stated that if PBL were implemented as a replacement to traditional direct instruction, students may become bored or may not have an opportunity to pull together the mathematics they have learned in an individual, formal setting. As such, another implication of this study is that, in order to maximize engagement and learning, students need a variety of experiences in mathematics and science classrooms, including PBL.

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