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Growing STEM Roots: Preparing Preservice Teachers

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Abstract
This mixed-methods pilot study investigates elementary and secondary pre-service teachers' (n=12) mathematics and science content knowledge and conceptions of nature of science following the first year implementation of a science and mathematics site-based professional development program. This study utilized pre/post data from science and mathematics content exams, and Views of Nature of Science-C instrument. Data revealed gains in preservice teachers' mathematics and science content knowledge and perceptions regarding the nature of science.

Introduction

The shortage of STEM (science, technology, engineering, and mathematics) middle school teachers, especially those in low income and high minority schools, is exacerbated by the fact that many of the teachers are not adequately prepared or supported to foster success and interest in science and mathematics (Boyd, Lankford, Loeb, Ronfeldt, & Wyckoff, 2011). This study explored designing teacher preparation with authentic research experiences combined with site- and content-specific professional development. Field based experiences utilized inquiry and other tools to increase content understanding and deepen views of the nature of science.

The purpose of this paper is to describe a mixed-methods pilot study investigating elementary and secondary pre-service teachers' mathematics and science content knowledge and conceptions of nature of science following the first year implementation of a science and mathematics site-based professional development program. The key elements of this transformative strategy for bolstering the elementary to middle levels science and mathematics teaching certification pathway for preservice teachers will be discussed. Findings in this study will offer insight regarding fostering and developing preservice teachers' math and science
content knowledge and understandings of nature of science in teacher preparation programs.

Literature Review

Generalist elementary education degrees are among the most completed in the U.S. (NCES, 2012). However, many of these teachers have limited preparation for effectively teaching mathematics and science as they have usually completed only one to three content courses in generalist education programs (CBMS, 2012). Teachers who express uneasiness with mathematics or science are more likely to avoid planning or teaching these subjects (Newton, Leonard, Evans, & Eastburn, 2012). In addition, because educators struggle to adapt new curricula and new instructional techniques in their unique classroom contexts, just-in-time, job-embedded assistance was identified as crucial (Guskey & Yoon, 2009). Teacher preparation institutions must provide access to high quality mathematics education and

create supportive learning environments for preservice teachers (Capraro, Capraro, Parker, Kulm, & Raulerson, 2005). Furthermore, engaging preservice teachers in authentic, situated practices of science and science teaching provides a productive context to learn about the nature of science (Schwartz, Lederman, & Crawford, 2004).

Traditional teacher education programs often lack authentic connections between university-based teacher education courses and K-12 field experiences (Zeichner, 2007). Additionally, student teachers usually do not have opportunities to observe, try out and receive focused feedback about their teaching of methods learned in college courses. Darling-Hammond (2009) identified this lack of connection as the Achilles' heel of teacher education. Preservice teachers are typically left to work alone with little guidance relating activities to coursework. Furthermore, it is often assumed that good teaching practices are personally identified as they occur, rather than taught in an authentic, situated context (Darling-Hammond, 2009; Valencia, Martin, Place, & Grossman, 2009). A possible solution to these challenges is to prepare elementary and secondary teachers for grades 4-8 STEM instruction and the certification process by augmenting their science and mathematics content knowledge.

Program Description

Project Overview

South Texas University (pseudonym) is testing an unconventional and transformative strategy for bolstering the elementary to middle levels science and mathematics teaching certification pathway for preservice teachers. As a nationally funded, research-based effort, a team of investigators are studying the impact of a new program initiative by using a mixed-methods matched-group research design addressing students, pre- and inservice teachers in relation to views on nature of science, as well as self-efficacy, interest, and achievement in science and mathematics as indicators of the quantity, quality, and diversity of grades 4-8 mathematics and science teachers. The purpose of this paper is to highlight initial findings using case-based studies to investigate preservice teachers' changes in mathematics and science content knowledge and views of NOS in a site-based professional development program.

During the 2013-2014 academic year, the 30-year teacher preparation partnership consisting of the largest school district and university in a mid-sized U.S. southern city, began implementing the new program at three participating schools, including one middle school and two elementary feeder schools serving a combined 1,900 students annually. Given the deficits identified in the effectiveness of traditional, externally designed professional development and the lack of authenticity in college preservice field-based experiences, program investigators created a new model for science and mathematics content instruction by incorporating site- and content-specific professional development with field-based experiences, using inquiry and other tools to increase authenticity. The key elements of the site-based professional development program includes a stronger partnership between the university and school district, a partnership with preservice and inservice teachers, implementation of research-based instructional practices in lesson planning sessions and workshops, and incorporating hands-on, active-learning experiences and strategies specific for each classroom situation.

This study addressed the following research questions: 1) To what extent did pre-service teachers' mathematics content knowledge change over the program period? 2) To what extent did pre-service teachers' science content knowledge change over the program period? 3) To what extent did pre-service teachers' views of `the nature of science change over the program period?

Methods

Context of the Study

The College of Education teacher preparation program's enrollment predominantly consists of preservice teachers seeking their early childhood/elementary teacher, grades EC-6 certification. Hence, the target population for this study was elementary preservice teachers in urban settings. Additionally, the program was offered to middle grades mathematics majors with the goal of them adding on a middle grades science certification. The EC-6 preservice teachers were enrolled in an undergraduate teacher preparation program and had taken three math foundation courses and two science foundation courses as part of their required courses. The middle grades mathematics majors had the same foundational courses in math and science as the elementary preservice teachers. The 4-8 mathematics majors had an additional 19 credits of mathematics coursework. The preservice teachers participated in this research study during their required year-long field experience, the final year of their program.

The first semester of preservice teachers' field experiences is the field based course, which focuses on the pedagogy and professional competencies of teachers. The course is comprised of students from a variety of disciplines. Therefore, the pedagogy component is not specific to the students' major field of study. The field based course is hosted on-site at a K-12 school campus (partner school) and taught by a university site professor. The preservice teachers spend two days per week for 14 weeks working with their university site professor on pedagogical skills and time in assigned K-12 classrooms implementing teaching strategies and techniques with students. The second semester of field experiences is the student teaching semester, where preservice teachers spend five days a week for 14 weeks in a research partner school. In addition to field basing and student teaching, participants met after school to plan three inquiry-based lessons for STEM Thursday. The research participants were assigned to research partner schools and took their field-based courses over consecutive Fall-Spring semesters. In addition, participants received compensation for their participation. All preservice teachers' names have been replaced with pseudonyms.

The professional development efforts centered directly on providing authentic experiences in mathematics and science to enhance preservice teachers' mathematics and science content knowledge and their understandings of NOS and scientific reasoning (Abd-El-Khalick & Lederman, 1998). The program's professional development model consists of: 1) common planning 2) STEM Thursdays 3) certification workshops and 4) authentic research experiences.

Common Planning. There are two common planning sessions held at each partner school per semester, for a total of six planning sessions led by university faculty during each semester. The common planning sessions offer a unique opportunity for mathematics and science inservice teachers to work alongside each other to plan collaborative lessons as they mentored preservice teachers. During the first part of the common planning sessions, preservice teachers and inservice mathematics and science teachers participate in professional development activities ranging from mathematics concepts and problem solving to inquiry-based teaching and nature of science understandings. During the second part of common planning time, the preservice teachers, inservice teachers, and university faculty meet around large tables and work collaboratively to plan integrated mathematics and science lessons for STEM Thursdays. During these collaborative planning sessions, discussions arise about best practices in teaching various concepts, inquiry-based lessons, nature of science, manipulatives utilized by instructors, and experiences from the authentic science research activities. These common planning sessions provide preservice teachers with additional opportunities to enhance their content knowledge by directly interacting with their cooperating teacher and university faculty to increase their confidence in teaching the lesson concepts, as well as opportunities to learn vicariously through their peers.

STEM Thursdays. Another key component of the program model, STEM Thursdays, impacts all of the stakeholders (pre- and inservice teachers, science and mathematics faculty, 4-8 students). Three times per semester, participants receive hands-on and minds-on science and mathematics lessons with many conceived during common planning times. These lessons are implemented in grades 4-8 classrooms at all partner schools.

Certification Workshops. Preservice teachers participate in workshops on the university campus to increase their content knowledge in mathematics and science during the Fall and Spring semesters. There are six mathematics and six science certification workshops provided for preservice teachers each semester, for a total of 12 workshops led by university faculty and master teachers. During the workshop sessions, the focus is to help preservice teachers understand and reinforce concepts in mathematics and science.

Authentic Research Experiences. Preservice and inservice teachers participate in original science research with university researchers, experiencing science as they work in the field and lab. During the Fall semester, preservice teachers participated in 10 hours of authentic research experiences in the university's College of Science and Engineering working with university researchers and scientists to learn about science, the nature of science, and how scientists conduct their investigations in the field and lab.

Setting and Participants

Three partner schools are affiliated with the program: two elementary school campuses and one middle school campus. Of the three research partner schools, the site-based professional development took place at only one of the three school campuses, a middle school campus, which serves grades 6-8 students (treatment group). The experiences of the preservice teachers at the middle school campus, who received the on-site professional development, was compared to the preservice teachers experiences at one of the elementary school campuses that serves grades K-5 students (control group).

The participants include 12 preservice elementary (n= 6) and secondary teachers (n=6), all females, participating in a science and mathematics site-based professional development program. For the purposes of this case study

approach, 4 of the 12 preservice teachers were randomly selected as a representative sample of the original preservice teacher study population. Therefore, the study participants (n=4) were part of a larger preservice teacher cohort. Two participants are prospective elementary teachers seeking an EC-6 generalist teaching certification and two are prospective secondary teachers, seeking a 4-8 math teaching certification.

Control group. The control group is representative of preservice teachers at the elementary school. The preservice teachers did not receive explicit teachings on nature of science or the 5-E (Bybee, Taylor, Gardner, Scotter et al., 2006) inquiry-based instructional model. In preparation for STEM Thursday activities: (a) math and science lessons were given to preservice teachers during a single meeting with a science and/or mathematics faculty member, (b) preservice teachers taught lessons once in 4th and 5th grade classrooms, (c) program staff developed and led the lesson lessons, and (d) preservice teachers had a supporting role. At the elementary school campuses, STEM Thursday math and science lessons were only taught once, as opposed to teaching the lessons to multiple classes throughout the day.

Treatment Group. The treatment group is representative of preservice teachers at the middle school. The site-based professional development consisted of: monthly planning meetings, enhanced STEM Thursdays, onsite support, and materials and resources. Preservice teachers received explicit teachings on nature of science, science content, and 5-E inquiry-based instructional models. In preparation for STEM Thursday activities: (a) preservice teachers and program staff collaboratively planned and created 5-E math and science lessons, (b) preservice teachers led lessons and program staff acted in supporting role, (c) preservice teachers taught lessons in consecutive periods in 6th and 7th grade classrooms, (d) preservice teachers and program staff met 3-4 weeks every month and exchanged emails, (e) preservice teachers practiced teaching their lessons prior to STEM Thursday, and reflected afterwards. On-site support from a science education professor was available twice per week.

Data Collection and Instruments

In this mixed-methods study, the researchers utilized three instruments as sources of data during the year-long intervention: a) mathematics content exam, b) science content test and, c) a modified version of the Views of Nature of Science (version C) questionnaire (Lederman, Abd-El Khalick, Bell, & Schwartz, 2002).

Content Tests

Researchers measured preservice teacher's mathematics content knowledge with a 25-item pre/post multiple choice mathematics content exam, addressing domains on the state's middle school mathematics certification exam. Preservice teachers' changes in science content knowledge was measured with a 25-item multiple choice pre/post exam (Wynne, 2008), devised and tested to establish validity and reliability (Miles & Huberman, 1994). The test represented the science teacher domains (scientific inquiry and processes, physical science, life science, earth and space science) addressed on the state science teachers certification exam.

VNOS-Form C

To assess preservice teachers' conceptions of nature of science, researchers administered the VNOS-C, a 10-item, open-ended questionnaire (Abd-El-Khalick and Lederman1998) later revised (Lederman, Abd-El Khalick, Bell, & Schwartz, 2002). Per authors suggestions (Lederman, Abd-El Khalick, Bell, & Schwartz, 2002), each VNOS-C item was printed on a single page to provide respondents with adequate space for their responses. Researchers encouraged participants to elaborate and provide supportive illustrations where applicable. For this study, researchers evaluated 5 of the 10 questions from the VNOS-C questionnaire targeting the following nature of science aspects: a) empirical nature of scientific knowledge; b) distinctions and relationships between scientific theories and laws; c) the creative and imaginative nature of scientific knowledge; and d) the cultural and social influences of scientific knowledge. Analysis utilized a rubric based on previous research (Bargmann & McCollough, 2011). Researchers independently reviewed and scored the VNOS-C participant responses and achieved a 90% agreement rate. A qualitative analysis of questionnaire responses measured preservice teachers' conceptions of nature of science (Creswell, 2007). Additional qualitative data included focus group responses conducted by external consultants resulting in transcribed participant responses. Data analyses were discussed and differences were resolved reaching consensus among the researchers (Miles & Huberman, 1994).

Results and Discussion

Results are organized by the three research questions and case-based studies of the four participants which included the following data:

Mathematics content knowledge. Overall, 9 of 12 (75%) preservice teachers improved in the pre-post measure of mathematics content knowledge (see Figure 1). It is important to note that preservice teachers in the control group and treatment group differed in mathematical ability. Preservice teachers in the treatment group were seeking secondary mathematics teaching certificate, and had taken more mathematics courses providing a higher level of content knowledge in mathematics than the control group. The control group made larger gains (15%) than the treatment group (13%). However, the control group made gains that were quite variable. Gains ranged from -23% to 67%, indicating the intervention may not have significantly helped this group. Conversely, the treatment group made gains from 4% to 27% and participants consistently improved.

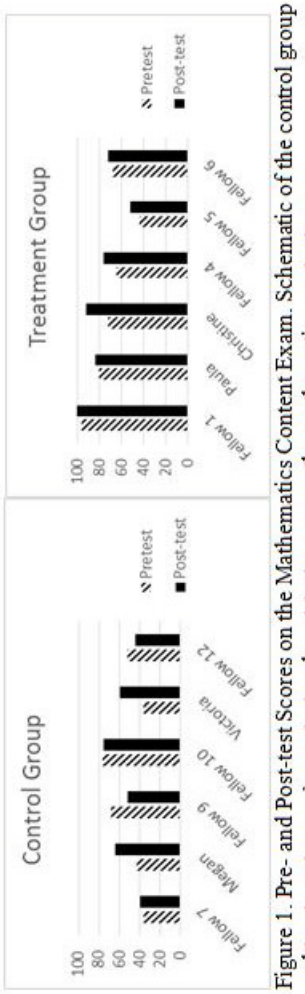

Figure 1. Pre- and Post-test Scores on the Mathematics Content Exam. Schematic of the control group and treatment group's pre-test and post-test scores on the mathematics content exam.

Table 1
Summary of Scores on the Mathematics Content Exam

	Pretest score		Posttest score		Normalized gains (%)		Raw gains (%)	
	Control	Treatment	Control	Treatment	Control	Treatment	Control	Treatment
Mean	51.67	70.67	56.00	79.33	15.21	13.29	4.33	8.67
Median	47	70	56	80	5.56	12.03	2	6
St. Dev.	16.99	17.28	13.39	16.86	36.65	9.70	16.02	6.41
Min	36	44	40	52	-23.53	4.17	-16	4
Max	76	96	76	100	66.67	27.78	24	20
N	6	6	6	6	6	6	6	6

Note. N=12. The summary of pretest and posttest scores on the mathematics content exams are represented in percentages.

Science content knowledge. Overall, 8 of 12 (67%) preservice teachers in Year 1 improved on the pre-post measure of science content knowledge as shown in Figure 2. According to the pre-test results the six middle school preservice teachers in the program entered the professional development program with greater science knowledge (M = 0.52, SD = .20) than the elementary group (M = 0.42, SD = .16). The treatment group showed normalized gains of 29%. The control group had normalized gains of 7%, a significant increase in post-test scores. A Mann-Whitney test compared differences between the control and treatment groups and revealed a significant difference between

the distribution of the post-test scores (p = .015). For normalized gains, Cohen's d = .71, indicating a large effect size. Data supports the conclusion that the professional development model used at the middle school had a significantly strong impact on the acquisition of science content knowledge (Table 2).

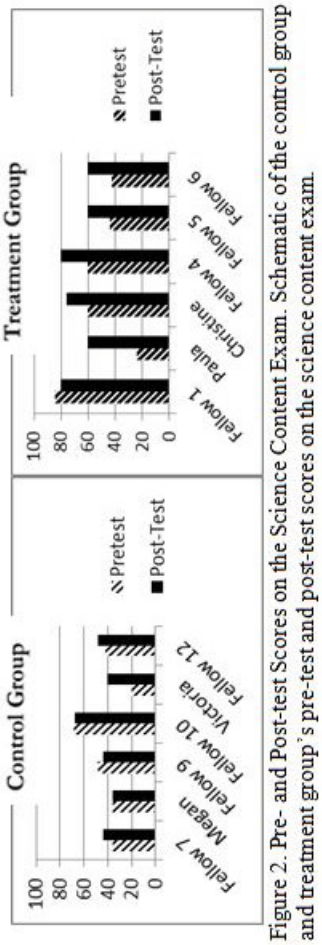

Figure 2. Pre- and Post-test Scores on the Science Content Exam. Schematic of the control group and treatment group's pre-test and post-test scores on the science content exam.

Table 2
Summary of Scores on the Science Content Exam

	Pretest score		Posttest score		Normalized gains (%)		Raw gains (%)	
	Control	Treatment	Control	Treatment	Control	Treatment	Control	Treatment
Mean	0.42	0.52	0.47	0.69	0.07	0.29	0.22	0.47
Median	0.39	0.52	0.44	0.68	0.05	0.36	0.07	0.35
St. Dev.	0.16	0.20	0.11	0.10	0.12	0.28	0.40	0.53
Min	0.20	0.24	0.36	0.60	-0.08	-0.25	-0.08	-0.05
Max	0.68	0.84	0.68	0.80	0.25	0.50	1.00	1.50
N	6	6	6	6	6	6	6	6

Note. N=12. The summary of pretest and posttest scores on the science content exams are represented in percentages.

Nature of Science. Analysis of the qualitative component of the written response shows that the two groups had similar initial responses to the VNOS-C, in which a majority of the preservice teachers held naïve conceptions of the nature of science. Middle level preservice teachers had fewer misconceptions about nature of science when compared to more informed views of the elementary preservice teachers who had modest gains, but did not respond with fully informed answers to any of the questions (Figure 3)

Item	Question	1 = Naïve, 2 = Informed
		Targeted NOS Aspect
1	What, in your view is science? What makes science different from other disciplines of inquiry?	Empirical NOS
2	Is there a difference between a scientific theory and law? Illustrate your answer with an example.	Theories vs. Laws
3	After scientists have developed a scientific theory, does the theory ever change? If so, how? If not, why not?	Nature of theories/ scientific claims
4	Do scientists use their creativity and imagination during their investigations?	Creativity and imagination
5	Does science reflect social and cultural values? Explain why and how. If you believe science is universal, explain why and how.	Social and cultural

Figure 3. VNOS-C Questionnaire Items Utilized for Pilot Study

Case-based Studies of Participants

Paula. Paula is a non-traditional student pursuing teaching as a second career and does not speak English as her native language. Her math score increased 4% and science content test post-score increased 150%. Paula's VNOS-C post-test response depicts an increased understanding that science is based on experimentation and the collection of data. In her pre-test, Paula revealed common misconceptions about theories and laws including the belief that a theory can be proved true; once it does, it turns into a law. In her post-test, Paula was able to provide an example of a law.

Christine. Christine demonstrates strong leadership abilities and is extremely enthusiastic about teaching both math and science. Her math score increased 20% and science score increased 27%. Christine's multiple choice question score increased 27%. Her VNOS-C scores also increased in two of the five questions. Christine had similar misconceptions as Paula when she began the program. In her post-test, Christine revealed a more developed understanding of the nature of science and was able to provide Newton's Laws as a concrete example of a scientific law.

Megan. Megan is an EC-6 major who was pursuing an add-on certificate in both math and science. She student taught in a self-contained fourth grade classroom. Her math score increased 22% and scores on the science content exam remained the same for both administrations. Her VNOS-C response showed growth in only one nature of science aspect, understanding of the role of creativity.

Victoria. Victoria was assigned to a fifth grade Language Arts classroom for student teaching. She did participate in the planning and delivery of five science and mathematics lessons during her experience. Her math score increased 24%. Her prior science content knowledge measured 20% on the pre-test and grew to 40% during the year. Her VNOS-C scores did not show any growth in understandings of nature of science.

Conclusion

Data from this study concludes that preservice teachers' knowledge and views of mathematics and science deepened over the course of the year-long professional development as they made connections between their experiences as learners and as teachers. There were modest gains in mathematics and science content knowledge and the program afforded a stronger partnership with preservice teachers, allowing them to explore inquiry-based mathematics and science alongside scientists, mathematics educators and science educators, and becoming familiar with their conceptions of the nature of science.

Explicit nature of science instruction utilized in the middle school professional development model had a significant impact on science content knowledge and modest gains in nature of science understandings. Promoting teachers' understanding of nature of science is necessary for effective science teaching and must include explicit scientific reasoning and scientific training as part of elementary and secondary science methods courses. Preservice teachers' mathematics and science content knowledge can be developed by working collaboratively with peers, inservice teachers, and university faculty to write lesson plans, teaching, reflecting on teaching practices, and learning to teach. A situated, authentic and relevant uncovering of mathematics and science content benefits all stakeholders – preservice teachers, inservice teachers, students, and mathematics and science faculty - as all supportively infuse a deeper level of understanding in these STEM content areas.

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