IMPACT OF A SCIENCE METHODS COURSE ON PRE-SERVICE ELEMENTARY TEACHERS' KNOWLEDGE AND CONFIDENCE OF TEACHING WITH SCIENTIFIC INQUIRY AND PROBLEM-BASED LEARNING

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Abstract

The purpose of this study was to measure the impact of an elementary science methods course on pre-service teachers' knowledge and confidence of teaching with inquiry and problem-based instructional strategies. Changes in pre-service teachers' knowledge and confidence were measured before and after completing the course activities using a pilot survey entitled "Science Pedagogical Content Knowledge & Confidence (PCKC) Survey." An integrated lecture/laboratory elementary science methods course engaged participants with hands-on activities designed to increase their pedagogical content knowledge: including theory, planning and implementation of inquiry, and problem-based learning. The results indicated that pre-service teachers' knowledge and confidence improved as a result of enrollment in the elementary science methods course. This article validates reform movements to incorporate scientific inquiry and problem-based learning into coursework.

Background

The 2012 "Program for International Student Assessment" (PISA) ranked U.S. students average in science and below average in mathematics among the world's most developed countries [1]. Similarly, the "Trends in International Mathematics and Science Study" (TIMSS) rank U.S. students behind many other developed nations [2]. Advocates for educational reform focus on teacher preparation as essential to improving the quality of science teaching and learning.

The Journal of Mathematics and Science: Collaborative Explorations Volume 15 (2015) 33-52

The essential components of teaching elementary science are pedagogical skills, content knowledge, and the confidence and willingness of teachers to assume responsibility for student learning. The 2002 National Science Teachers Association (NSTA) position paper recommends that "inquiry science must be a basic in the daily curriculum of every elementary school student at every grade level" [3]. Although the NSTA and other science professional organizations advocate use of inquiry in teaching science, very few elementary school teachers, especially beginning teachers, engage in this teaching strategy [4]. Zeichner and Tabachnick found that beginning teachers switch from progressive, student-centered strategies and attitudes formed during pre-service training to traditional, teacher-centered approaches when faced with the difficult realities of teaching [5]. Such difficulties include the following areas:

1) Unfamiliarity with science as a discipline;
2) Lack of science content knowledge;
3) Low self-efficacy with respect to science teaching;
4) Difficulties in assessing results of inquiry learning;
5) Classroom management issues; and,
6) Dominant commitment to preparing students for standardized testing [6].

Of these reasons, the first five are interconnected, and can be addressed by modifying the way in which pre-service teachers are trained in preparation programs. Appleton and Kindt found that beginning teachers are prone to undertake "safe" activities first (e.g., activities with predictable outcomes and/or drawn from personal experience or that of colleagues) [4]. Therefore, if such individuals have experienced science as largely book research and memorization in their own schooling, they will tend to see these activities as safe and effective. In comparison, those individuals exposed to the excitement of hands-on, inquiry-based science activities would likely see these activities as safe and effective. One of the recommendations from the Appleton and Kindt study is that education curriculum should focus on providing pre-service teachers with a repertoire of activity ideas that develop science pedagogical content knowledge [4].

Pre-service teachers who have had positive, authentic inquiry experiences during their school years and/or teacher preparation programs demonstrate improved dispositions and self-efficacy for science teaching [7-10]. In 2004, the Association for Science Teacher Education (ASTE) issued their publication, "Position Statement: Science Teacher Preparation and Career-long Development" which made the following recommendations for pre-service teachers:

> ...engage in activities that promote their understanding of science concepts and the history and nature of science; experience strategies for effective science teaching and inquiry, including meaningful laboratory and simulation activities using contemporary technology tools; question and evaluate evidence and justify assertions scientifically; and, develop science-specific pedagogical knowledge grounded in contemporary scholarship [11].

Unfortunately, the literature indicates that training in inquiry and problem-based instructional strategies is not consistently incorporated into the education curricula for pre-service teachers. Most teachers have never been exposed to actual inquiry unless they have previously engaged in scientific research [12, 13]. For these reasons, the authors infused a science methods course for pre-service elementary teachers with science-specific pedagogical content knowledge, including the theory, planning, and implementation of inquiry and problem-based learning.

Participants and Context

This study was facilitated during a 15-week instructional period during the Fall 2013 semester at a small liberal arts college in southeastern Virginia. All of the participants were enrolled in the science methods course and were in their junior or senior year of college. Each student was seeking a four-year Bachelor of Science degree that leads to teacher licensure. The elementary science methods course integrated the lecture and laboratory activities, met twice weekly for 2.5 hours, and included a practicum experience. The demographic of the participants included 17 African-American females, 2 Hispanic females, 1 Caucasian female, and 1 African-American male.

Two of the authors participated in the Virginia Initiative for Science Teaching and Achievement (VISTA) Science Education Faculty Academy (SEFA) during the summers of 2012 and 2013. Prior to the Academy, the science methods course involved pre-service teachers with the investigation of and participation in the science process skills. Investigatory activities were completed each week in the scientific areas of earth sciences, biology, chemistry, and physics. Other course activities included science safety in the classroom and integrated teaching.

As a consequence of the training, the science methods course was revised to adopt the VISTA goal of exposing elementary teachers to "scientific, problem-based learning and student-centered inquiry as they work in teams to conduct inquiry-based science for children" [14]. As indicated by the syllabus, the revised course emphasized SEFA topics, including hands-on learning, inquiry, Problem-Based Learning, Nature of Science, Next Generation Science Standards, scientific discourse, and engineering design briefs. The authors selected the course textbook *Ready, Set, Science!: Putting Research to Work in K-8 Science Classrooms*, and many of the assigned journal readings were based on their SEFA experiences [15].

Table 1
Science Methods Course Schedule

Dates	Topics	Journal Readings
Week 1	Introduction and Course Overview and Expectations	
Week 2	STEBI-B, PCKC Survey, Science Content Assessment, and Focus Groups	
Weeks 3 & 4	Nature of Science, Hands-on activities; Inquiry-based learning; National, state, and local science standards;	*The Nuts and Bolts of Introducing Science Notebooks Into Your Science Teaching Practice*
Week 5	Teaching the Nature of Science; Scientific Discourse	*Executive Summary on the Nature of Science; Talking Science; Establishing Classroom Norms for Discussion*
Week 6	Science process skills; 5E Learning Cycle; Assessing Science Learning	*Engaging Elementary Students in STEM Summer Camp*; *How Classroom Assessments Improve Learning*
Week 7	Problem-Based Learning; Integrating Science across the Curriculum; midpoint PCKC Survey; Midterm Exam Assessment	*Modeling Problem-Based Instruction; Weather Tamers; Motor Mania: Revving Up For Technological Design*
Week 8	Science and Engineering	*Science and Engineering*
Week 9 & 10	Problem-Based Learning Unit Presentations	
Weeks 11 - 14	Class suspended for Practicum	
Week 15	Post-STEBI-B, Post-PCKC Survey, Focus Groups Practicum Reflections Final Exam Assessment	

At the start of the semester, pre-service teachers were provided with the VISTA definition of Hands-on Learning as "Students purposefully manipulating *real science materials* when safe and appropriate in a way *similar to a scientist*," and Inquiry as the "careful and systematic method of asking questions and seeking explanations" [16, 17]. The National Science Education Standard (NSES) model of the essential five features of inquiry in the classroom was utilized as a guideline for development of inquiry activities [18].

Table 2
NSES Essential Features of Inquiry

Essential Features of Classroom Inquiry and Their Variations				
Essential Feature	**Variations**			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2. Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulate explanations from evidence	Learner formulates explanations after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use sharpen communication	Learner given steps and procedures for communication
More ←------------------------ *Amount of Learner Self-Direction* ------------------------→ *Less*				
Less <------------------ *Amount of Direction from Teacher or Material* ------------------> *More*				
Source: National Research Council. 2000. Inquiry and the National Science Education Standards: A Guide for Teaching and Learning. Washington, DC: National Academy Press, 29.				

The goal of the science methods course was to provide science pedagogical content knowledge. Although students take twelve credit hours of science during this program, time limitations did not allow the instructor to address specific gaps in science content knowledge during this one-semester course. It is well accepted that relevant coursework in science and teacher content knowledge is a strong indicator in predicting science achievement of their students [19]. If teachers do not know the Science, Technology, Engineering, and Mathematics (STEM) content, then most students will not learn it [20].

The science content discussed in this methods course was broad and encompassed physical, chemical, and biological science. Pre-service teachers were given the tools to identify and remediate specific areas of science content weakness. At the beginning of the semester, the pre-service teachers were given a science content assessment based on Virginia's grade 5 *Standards of Learning* (*SOL*) science test release items. As a follow-up activity, pre-service teachers registered for and explored the resources on the NSTA Learning Center [21]. They were advised to complete the professional development indexers to diagnose specific science content needs and remediate areas of weakness using SciPacks.

The semester began with a pendulum inquiry experiment in which pre-service teachers were given one of two investigative questions: "What is the effect of string length on the period of a pendulum?" and "What is the effect of bob mass on the period of a pendulum?" Working in teams of four, they were challenged to propose a hypothesis and then develop the experimental design that would test the effect of string length and mass on the period of the pendulum. Assistance provided by the instructor was intentionally limited to allow the pre-service teachers to brainstorm ideas. The experimental design was an enormous challenge because their only prior experience with science had primarily been following "cookbook labs." These very prescriptive labs teach basic skills, such as using scientific equipment, measuring, observing, inferring, etc., but they rarely support inductive reasoning, inquiry, or the authentic nature of science [22]. The pre-service teachers were further challenged to determine the type of data needed to address their hypothesis, to analyze their data beyond superficial observations, and to make relevant conclusions. Initially, class discussions were limited to "my results support my hypothesis" or "my results do not support my hypothesis." They struggled with understanding the significance of their results and were obsessed with knowing whether their results or answers were "right or wrong."

In a follow-up activity, the pre-service teachers were randomly given existing cookbook lab exercises and tasked with converting them into inquiry, student-centered activities following the method of Corder and Slykhuis, i.e., replace, retain and modify, and remove [23]. The pre-service teachers replaced standard introductory descriptions and background information with investigative questions. The class definition of an effective investigative question was one that has something to measure and/or compare. Next, they modified the procedure by simplifying the directions, but retained the investigative parameters and safety guidelines. Finally, they removed the results tables to allow students to create their own methods for organizing data. For each converted lab, the pre-service teachers had to anticipate their students' potential responses by developing procedures for each investigative question and data tables for the results. Table 3 is an example of a converted lab. The pre-service teachers seemed to appreciate learning that developing inquiry labs from existing lab procedures need not be complicated or intimidating.

Table 3
From Cookbook Lab to Inquiry Lab

Example Cookbook Lab – Static Electricity Background: Rubbing a balloon creates a buildup of negatively-charged electrons on the surface called static electricity. Electrons can pull very light positively-charged items toward them. Specific procedure: 1. Place an empty aluminum can on its side on a table. 2. Blow up a balloon, and rub it back and forth through your hair really fast. 3. Hold the balloon close to the can without actually touching the can. Static electricity will roll the can toward the balloon. 4. Measure and record the distance moved in millimeters.
Example Inquiry Lab – Static Electricity Demonstrate the cookbook lab to students during the anticipatory set to promote student-directed development of investigative questions. Potential investigative questions that might be developed by students: • What effect does balloon size have on the power of the pull? • Are there materials other than hair that cause static electricity? • Will all types of hair cause static electricity? • Will the balloon pull all types of cans? • Will the balloon pull other items? • How strong is the pull of the balloon? • Can water be added to the can? How much water can be added until the balloon can't pull it anymore? Materials

- Assortment of materials to test for developing static electricity: wool, cotton and other fabric materials; human and artificial hair.
- Assortment of materials to test the strength of the pull: cans of different sizes and materials, packing peanuts, tissue paper, etc.
- Water.

Directions:

1. Design and conduct an experiment to answer your investigative question.
2. Be mindful of all the class safe laboratory procedures.
3. Record the data in a manner that allows you to share with the class.

At the semester midterm, the pre-service teachers were tasked with individually developing lesson plans aligned with a Virginia Science *SOL* and incorporating the NSES essential five features of inquiry. They were encouraged to examine existing lesson plans on specific websites and modify them to meet the assignment. Similarly, as noted in the findings of Yoon, Joung and Kim, the pre-service teachers were uncertain in their "decision making in when and what to guide, and what to leave open" in the development of these inquiry lessons, particularly for K-3 lesson plans [24]. The pre-service teachers struggled most with creating inquiry lessons in which the actual answer to investigative questions might not be immediately known, or for which multiple solutions were possible. This discomfort undoubtedly stems from the fact that many of their prior laboratory experiences had been cookbook lab activities, where there was only one predetermined, possible answer to the "research" question. During in-class constructive feedback from the authors, they were able to make improvements to their lesson plans. Unfortunately, time limitations of the course did not allow the pre-service teachers to teach their lesson plans.

The science methods course utilized Problem-Based Learning (PBL) as a curricular approach or framework for structuring science content into a unit of study. The pre-service teachers were given the VISTA definition of PBL as "Students solving a problem with multiple solutions over time like a scientist in a real-world context" [17]. Examples of Problem-Based Learning were introduced to the pre-service teachers using the VISTA journal articles, "Modeling Problem-Based Instruction," "Weather Tamers," and "Motor Mania: Revving Up For Technological Design" [25-27]. A great deal of time was spent on examining the essential elements of effective PBL lessons. Emphasis was placed on making the PBL lessons authentic and meaningful to students, using community settings and/or partners, and embedding Virginia *SOL* science content into a course of study over two to five weeks.

As a classroom project, pre-service teachers worked in teams composed of three to four students to create a PBL unit appropriate for an elementary grade science class. The assigned VISTA articles served as the template for development of these PBL lessons. Groups were encouraged to use any curriculum resources and materials available. Inquiry activities did not have to be original; however, they had to allow students to ask scientific questions, collect evidence, develop explanations, and communicate solutions justified by evidence. In groups, pre-service teachers presented the components of the PBL unit to the science methods class for evaluation and feedback.

Pre-service teachers were placed into local elementary school settings for a four-week practicum during the last one-third of the science methods course. They were instructed to observe science lessons, and determine the degree to which the mentoring teachers incorporated the instructional strategies discussed in the science methods class. Each pre-service teacher interviewed his/her mentor teachers to determine what s/he believed are the key factors and challenges of teaching science. They interviewed the students to find out what students like or dislike in learning science. A course written assignment required the pre-service teachers to summarize their observations and interviews, and to reflect on how the practicum impacted their feelings on teaching science in elementary school. Practicum experiences and reflections were shared with peers during the last week of the science methods class.

Methodology—Analysis of Results

Instrumentation — In this study, the participants completed a pilot survey entitled, "Science Pedagogical Content Knowledge & Confidence (PCKC) Survey," developed by the authors of this study. The purpose of this Survey was to evaluate self-reported levels of confidence in the pre-service teachers' ability to teach science and their knowledge for science teaching. This Survey was developed around the idea that the two constructs, confidence and knowledge, are needed for successful science teaching (see Appendices A and B). The items were written and selected based on the information presented in the elementary science methods course. The Survey contained twenty items related to the pre-service teachers' *knowledge* of the content and twenty items related to *confidence* in their ability to teach the subject. The Survey asked participants to rate themselves on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). A pre-test administration of the Survey occurred in August, while the post-test occurred in December of the same semester. Initial reliability measures were calculated. The construct of *knowledge* had a Cronbach's alpha of α = .78, while the construct of *confidence* provided a result of α = .77. An overall measure of internal consistency was also calculated and the instrument was found to have a reliability measure of α = .88.

Procedures — In the first week of the course, the participants received a briefing about the study, and were asked to provide consent for participation. The pre-test administration of the PCKC Survey served as a benchmark indicating the participants' belief in their confidence for teaching with scientific inquiry and Problem-Based Learning. In the semester course, the pre-service teachers were exposed to various tasks and activities that were designed to expose them to these instructional strategies. The coursework was explained in a previous section. The post Survey was given before midterm because these activities were held in the first half of the semester. The author wanted to make sure the pre-service teachers completed the Survey in a time period close to their actual experience with these specific instructional strategies in the methods course.

Analysis of Results— Results of the PCKC Survey were examined by individual construct and then in its entirety. The twenty items related to participants' *knowledge* in teaching science were examined to determine differences between pre-test and post-test results. Of the twenty items, only one (item 19) did not demonstrate an increase in the overall mean from pre-test to post-test. This item asked pre-service teachers to rate their knowledge in effectively utilizing technology (in addition to *PowerPoint*) when teaching. The pre-test mean for item 19 was 4.37, while the post-test mean was 4.33. However, the standard deviation did decrease, which would indicate that the spread of scores varied less in the post-test than in the pre-test administration (pre-test SD = .831, post-test SD = .730). This result may not be surprising as millennial-age college students are believed to have an advanced understanding of the use of technology. An examination of overall standard deviations for the twenty items related to *knowledge* found that two items (items 10 and 14) demonstrated an increase in the variance of responses as indicated by the standard deviation. The standard deviation pre-test for item 10 was .702, while the post-test was .921. For item 14, the standard deviation in the pre-test was .653 while the post-test was 1.065. The remaining eighteen items demonstrated a decrease in the variance in scores from the pre-test to post-test.

Next, the twenty items for the construct of *confidence* were examined for differences from pre-test to post-test. For the twenty items specific to *confidence*, all demonstrated an increase in ratings from the pre-test to post-test. Similar findings occurred when reviewing differences in the standard deviations from pre-test to post-test. Figures 1 and 2 denote the differences in means from pre-test to post-test for selected Survey items.

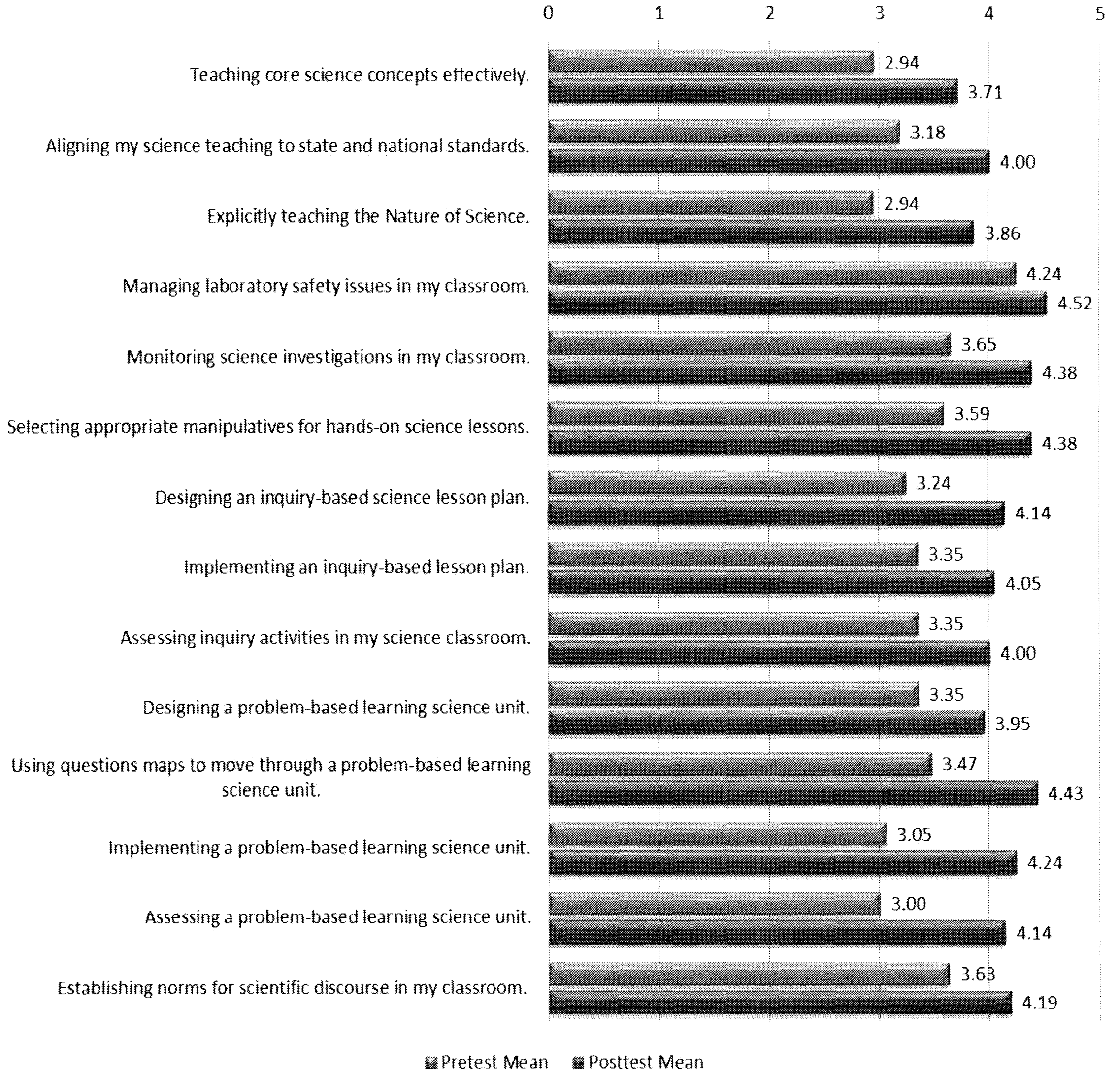

Figure 1. Likert scale ratings for completion of the phrase "I am knowledgeable about..."

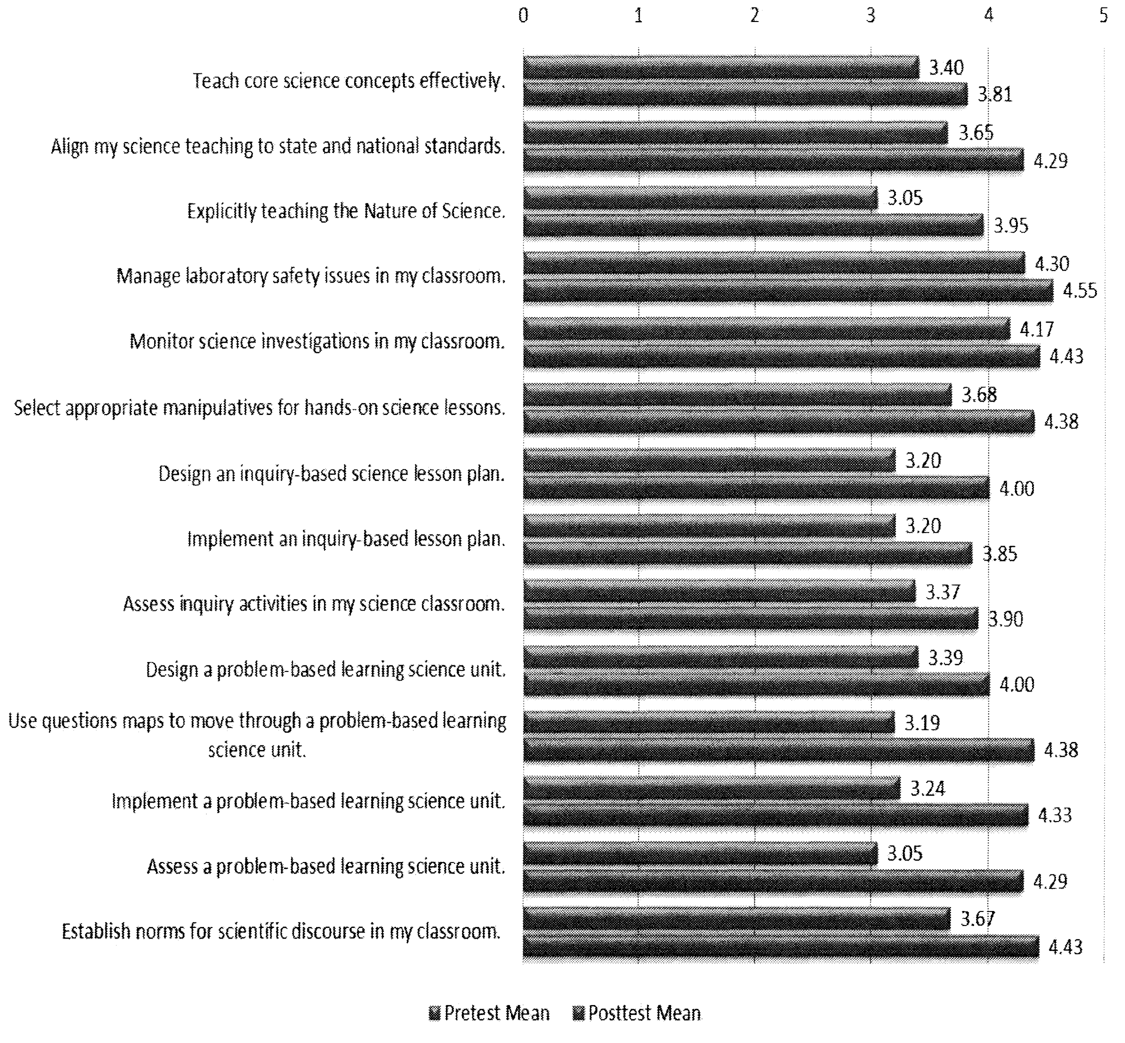

Figure 2. Likert scale ratings for completion of the phrase "I am confident in my ability to…"

The next analysis completed was the paired samples *t*-test. The paired samples *t*-test is run when comparing the means from a pre-test and post-test for the same group of participants. First, a paired samples *t*-test was run for the Survey items by construct. Results of the *t*-test for *knowledge* indicated a statistically significant difference between pre-test and post-test scores for the twenty items: $t(19) = -10.226$, $p = .000$). A second *t*-test was run for the items associated with the construct of *confidence*. Again, statistically significant results were found:

t(19) = -9.866, p = .000. Finally, a third *t*-test was run which was inclusive of all forty Survey items. Results indicated a significant result for the entire Survey, indicating that the participants' scores from the pre-test to the post-test had increased (t(39) = -14.403, p = .000). The mean for pre-test scores was calculated to be M=3.29, with SD=.549. Post-test scores were M=4.10, SD = .281.

Table 4
***t*-Test Results**

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Knowledge Pre-test Score-Post-test Score	-.86300	.37740	.08439	-1.03963	-.68637	-10.226	19	.000
Confidence Pre-test Score-Post-test Score	-.76250	.33718	.07540	-.92031	-.60469	-10.113	19	.000
Overall Pre-test Score-Post-test Score	-.81275	.35689	.05643	-.92689	-.69861	-14.403	39	.000

Overall, reliability measures confirmed internal consistency of the constructs, as well as the overall instrument. Individual means for the forty items for knowledge and confidence demonstrated gains from the pre-test administration to the post-test administration except for one item related to the construct of *knowledge*. The one item that did not produce a higher mean for the post-test was related to students' knowledge of the use of technology when teaching.

Discussion

Consistent with the literature, this study indicates science methods courses can improve the knowledge and confidence of pre-service elementary teachers to teach science. On the first day of class, the pre-service teachers expressed anxiety about their science knowledge and/or pedagogy. Their lack of confidence aligns with current research on the reluctance of elementary teachers to teach science [28, 29]. The overall results of the PCKC Survey do indicate significant differences from the pre-test scores to the post-test scores for the pre-service teachers enrolled in the science methods course. The pre-service teachers demonstrated enhanced knowledge and confidence of teaching with scientific inquiry and Problem-Based Learning. There was no initial assumption by the authors that pre-service teachers' knowledge would be higher or lower than confidence prior to the start of the study, or as a result of training received in the science methods course.

The pre-service teachers were introduced to the pedagogical content knowledge and then participated in group and/or partner activities that helped them "unpack" these concepts. As noted earlier, they were involved in creating specific activities on authentic scientific inquiry and problem-based learning. This pedagogy impacted the pre-service teachers' science thinking and learning because it encouraged them to engage in problem solving, decision making, collaboration, and critical thinking. Learning these skills enhanced their knowledge and confidence for future science teaching. These experiences, which incorporated the Virginia elementary science *SOL*, could easily be taught in an elementary school classroom. This format promoted learning that helped pre-service teachers see the practical applications of the content pedagogy, and understand the theory behind the practice.

Qualitative statements collected from participants as part of the Survey helped the authors discern the pre-service teachers' perceptions of their knowledge and confidence for teaching science in elementary school. One participant noted during the pre-test Survey, "[I don't] think I have enough knowledge about science to teach it effectively." At the end of the semester after participation in the PBL activities, she then stated, "I have been exposed to more effective methods of teaching." Another pre-service teacher initially felt, "I do not think I know enough to teach another person," but at the end of the semester, told the authors that "I can do anything I set my mind to." The authors feel that these changes were due to the interactive and "hands-on" nature of the course.

Simply providing educational theories or instructional strategies is insufficient to develop the necessary Pedagogical Content Knowledge (PCK) and skills [30]. Yoon and Kim demonstrated the importance of an inquiry-based teaching practicum for the development of elementary science teachers [24]. Following a four-week teaching practicum, pre-service teachers had the opportunity to reflect on their experiences. With few exceptions, most reported observing little or no inquiry science teaching in the elementary classrooms. Problem-Based Learning was not utilized in any of the school settings. The pre-service teachers found the practicum experience to be a weakness of the science methods course. This finding supports literature that indicates pre-service teachers often do not observe appropriate models of the inquiry-based science pedagogy during field base experiences [31]. The pre-service teachers wanted to observe implementation of the science methods course instructional strategies in the elementary school classrooms. As a recommendation for course improvement, they requested practicum placements in classrooms with mentoring teachers that have been trained in the VISTA program. They also wanted to develop inquiry lesson plans that could be implemented during their practicum. Findings by methods course instructors support allowing pre-service teachers to design PBL units for implementation in the classroom with the cooperation of veteran K-12 teachers [32]. It is expected that placement of pre-service teachers in classrooms with highly effective science teachers will be simplified once more teams of elementary teachers in the surrounding school districts participate in VISTA.

Acknowledgment

This work is partially supported by the National Science Foundation Broadening Participation Research Award (Grant No. 1238650).

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Appendix A
Construct of Knowledge

Sample constructs of the questionnaire: "I am knowledgeable about..."

1. teaching core science concepts effectively.
2. aligning my science teaching to state and national standards.
3. explicitly teaching the Nature of Science.
4. managing laboratory safety issues in my classroom.
5. monitoring science investigations in my classroom.
6. selecting appropriate manipulatives for hands-on science lessons.
7. designing an inquiry-based science lesson plan.
8. implementing an inquiry-based lesson plan.
9. assessing inquiry activities in my science classroom.
10. designing a problem-based learning science unit.
11. using question maps to move through a problem-based learning science unit.
12. implementing a problem-based learning science unit.
13. assessing a problem-based learning science unit.
14. establishing norms for scientific discourse in my classroom.

Appendix B
Construct of Confidence

Sample constructs of the questionnaire: "I am confident in my ability to…"

1. teach core science concepts effectively.
2. align my science teaching to state and national standards.
3. explicitly teach the Nature of Science.
4. manage laboratory safety issues in my classroom.
5. monitor science investigations in my classroom.
6. select appropriate manipulatives for hands-on science lessons.
7. design an inquiry-based science lesson plan.
8. implement an inquiry-based lesson plan.
9. assess inquiry activities in my science classroom.
10. design a problem-based learning science unit.
11. use question maps to move through a problem-based learning science unit.
12. implement a problem-based learning science unit.
13. assess a problem-based learning science unit.
14. establish norms for scientific discourse in my classroom.