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ELEMENTARY SCIENCE TEACHER EDUCATION

A Mile Wide or an Inch Deep? Improving Elementary Preservice Teachers' Science Content Knowledge Within the Context of a Science Methods Course

Alexandra O. Santau · Jaime L. Maerten-Rivera · Stephanie Bovis · Jacob Orend

Abstract Since the beginning of the reform movement in science education, there has been concern that elementary teachers lack the science content knowledge (SCK) needed to engage students in authentic scientific inquiry. This study included 19 preservice elementary teachers and examined the development of their SCK within the context of a uniquely designed elementary science methods course. A project-developed science knowledge test was administered at the beginning and the end of the science methods course, before and after science content was covered concurrent with modeled pedagogy. The preservice elementary teachers had adequate knowledge of low difficulty science content on the pretest, but demonstrated improvement on moderate and difficult science content, especially on topics emphasized in the methods course. Data analyses conducted on change in SCK using analysis of variance were statistically significant and demonstrated a large effect size. Details are discussed, along with large-scale implications and recommendations for elementary science teacher education.

Keywords Science content knowledge · Science methods course · Preservice elementary teachers · Elementary teacher preparation programs

Introduction

For several years now, US science education and the success of American students in Science, Technology, Engineering, and Math (STEM) has been lagging behind

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A. O. Santau (✉) · J. Orend
Duquesne University, 600 Forbes Avenue, Pittsburgh, PA 15282, USA
e-mail: santaua@duq.edu

J. L. Maerten-Rivera · S. Bovis
University of Miami, 1507 Levante Avenue, Room 222, Coral Gables, FL 33146, USA

that of other nations, despite the economic importance of science and math skills and education in the twenty-first century (Romberg, Carpenter, & Dremock, 2005). The 1983 publication of A Nation at Risk (Gardner, 1983), followed by the report Rising Above the Gathering Storm (National Academy of Science, 2005) some 20 years later, were pivotal in the development and implementation of new standards for science instruction based on recommendations made by the American Association for the Advancement of Science (AAAS, 1989, 1993) and the National Research Council (NRC, 1996, 2000). These standards, calling for improvements in student learning, program development, assessment, and professional development for teachers, were joined by the *No Child Left Behind Act (NCLB)* of 2001 (2002) (PL 107–110).

Since its implementation, *NCLB* has added to teachers' already rigorous responsibilities through the expectation of high academic achievement for *all* students. Especially high demands fall onto elementary teachers, who are educated as generalists to teach multiple subjects, yet are expected to teach life, physical, and earth sciences while engaging students in authentic scientific inquiry in order to provide students with a strong foundation of science content knowledge (AAAS, 1989, 1993; Krajcik & Sutherland, 2010; Michaels, Shouse, & Schweingruber, 2008; Nowicki, Sullivan-Watts, Shim, Young, & Pockalny, 2012; NRC, 1996, 2000; Osborne, 2010).

A significant number of studies suggest that there is a direct correlation between student achievement and teachers' preparedness to teach science (Darling-Hammond & Youngs, 2002; Krall, Lott, & Wymer, 2009; Wright, Horn, & Sanders, 1997). In addition, teachers with adequate science content knowledge (SCK) are more likely to teach through authentic inquiry (Davis, 2004). However, studies indicate that elementary teachers commonly report feeling uncomfortable, unqualified, and underprepared to teach science through inquiry, identifying the lack of adequate content knowledge as the root of the problem (Kind, 2009; Sharp & Hopkin, 2007; Weiss, Banilower, McMahon, & Smith, 2001). Consistent with elementary teachers' feelings, research has found that there are significant gaps in SCK (Burgoon, Heddle, & Duran, 2011; Dawkins, Dickerson, McKinney, & Butler, 2008; Kikas, 2004; Krall et al., 2009; Leite, Mendoza, & Borsese, 2007) and that frequently, elementary teachers harbor some of the same common science misconceptions as their students, which are difficult to change (Bulunuz & Jarrett, 2009; Burgoon et al., 2011; Bursal, 2012; Krall et al., 2009; Rice & Kaya, 2012; Stein, Larrabee, & Barman, 2008).

These considerations create the urgency to revisit the persisting concern over whether elementary teachers possess adequate science content knowledge and to find ways to best help teachers acquire this knowledge. Studies investigating the level of SCK among preservice and inservice elementary teachers have shown that elementary education programs do not prepare new teachers to teach science, especially not from a content perspective (e.g., Rice, 2005). Elementary teachers often view themselves as less prepared to teach science as compared to other subjects (Fulp, 2002), and only a small number of elementary teachers hold undergraduate majors in science or science education, eliminating the assumption that SCK might already exist (Weiss et al., 2001). Concerns that poor SCK will translate into low-quality teaching has led to a demand to improve science teacher preparation at the elementary levels, with the critical question of how and when to effectively deliver science content support to teachers.

The focus of the present study was to examine the change in SCK among preservice elementary teachers within the context of a science methods course designed to specifically address SCK as a usual shortcoming of elementary teacher preparation programs, as we consider SCK a foundational component to developing inquiry-based science pedagogy, or pedagogical content knowledge (PCK) in science. A standards-aligned science content pretest was administered prior to covering any science content or pedagogy, and a posttest was administered at the end of the semester after covering content and pedagogy. Nineteen undergraduate PreK-4 (early childhood) education students at a midsize university in the Northeastern United States completed both a pretest and a posttest. Specifically, the study addressed the following research questions:

1. How did preservice elementary teachers' SCK improve from pretest to posttest as measured by a knowledge test?
2. How did preservice elementary teachers' performance on specific test items vary from pretest to posttest?

Literature Review

Today's reform-based standards in science education stress that a teacher's capacity to effectively teach science consists of several essential components that must be developed and cultivated for teachers to succeed in our reform- and accountability-based educational world. Three important aspects of teaching science at the elementary level are discussed in the following literature review: (1) science content knowledge (SCK), *what* science to teach; (2) how the pedagogy to teach science depends on SCK; and (3) current aspects of elementary teacher preparation programs. Science content knowledge and pedagogy are critical in achieving scientific understanding (Blanchard, Southerland, & Granger, 2009; Romberg et al., 2005), thus investigating if and how these are fostered during teacher preparation programs is an important focus.

What to Teach: The Importance of SCK

For some time now, reform documents and research in science education have recommended that in order for teachers to effectively teach science to students, they should possess strong SCK (AAAS, 1989, 1993; Kennedy, 1998; NRC, 1996, 2000). Although most recent studies have heavily concentrated on PCK and much less on SCK, it has become consensus that teachers should possess complex understanding of science concepts, make connections among science concepts, and apply them to explain natural phenomena or real world situations (Gess-Newsome, Southerland, Johnston, & Woodbury, 2003; Kennedy, 1998; Lee, Luykx, Buxton, & Shaver, 2007).

Teacher SCK has a direct influence on the level of content-related discourse in the classroom, as teachers with weak SCK are more likely to pose low cognitive-level questions and foster low student participation (Carlsen, 1987). This in turn causes these teachers to (1) not sufficiently convey the meaning of scientific terminology and concepts to their students (Carrier, 2013), (2) compensate for lack of content knowledge through other means (Akerson, 2005), (3) spend more time "telling" science facts rather than allowing students to construct understanding through scientific inquiry (Newton & Newton, 2001), and (4) rely heavily on lecturing and textbooks, while avoiding student questions and classroom discussions (Abell, 2007). Conversely, teachers with greater SCK are more likely to generate beneficial classroom discussion, ask subject-relevant, causal, and higher-order thinking questions, and connect with real world experiences (Davis, 2004; Newton & Newton, 2001). Most importantly, teachers' SCK has a powerful effect on their use of inquiry-based practices and development of an investigative classroom culture (Luera, Moyer, & Everett, 2005; Supovitz & Turner, 2000), which is in line with recommendations of reform documents.

Studies have suggested that despite the ongoing reform in science education, elementary teachers have significant gaps in their SCK, may be poorly prepared to guide students in developing both science content and inquiry skills, and hold more similar conceptions to their students than to scientists, while often harboring the same misconceptions as their students (Burgoon et al., 2011; Dawkins et al., 2008; Kikas, 2004; Krall et al., 2009; Leite et al., 2007). Elementary teachers often do not feel confident in their SCK or competent to teach science (Adamson, Santau, & Lee, 2013), which can negatively affect their further development of content knowledge and ultimately their mastery of inquiry-based teaching (Nilsson & Van Driel, 2010).

These issues might be part of the reason teachers have reported reduced instructional time spent on science instruction (Griffith & Scharmann, 2008; Marx & Harris, 2006; McMurrer, 2007, 2008; Trygstad, 2013). When science instruction is limited at the elementary level, many teachers assume that children can catch up in science when they reach middle and high school (Milner, Sondergeld, Demir, Johnson, & Czerniak, 2011). However, quality science education at the elementary level is imperative to foster interest and to create a solid conceptual foundation upon which science learning can build, as elementary students exhibit unique characteristics including curiosity, flexibility to use a variety of reasoning processes, and understanding of scientific concepts that may not be as acute later in life (Eshach & Fried, 2005).

SCK is often subdivided into the domains of substantive knowledge and syntactic knowledge of science. Substantive knowledge involves organizing frameworks and dominant structures that guide inquiry, and "knowledge of general concepts, principles and conceptual schemes, together with the detail related to a science topic" (Anderson & Clark, 2012, p. 316). Syntactic knowledge refers to how new knowledge is incorporated into a subject area, the nature of science (NOS), and how scientific knowledge develops and becomes accepted, which occurs through inquiry (Anderson & Clark, 2012). In this paper, we refer to SCK in a general manner, but our data lends itself to investigating substantive SCK and not syntactic SCK.

PCK Depends on SCK

Many researchers and educators agree that it is not sufficient for teachers to know *what* to teach, but they must also know *how* to teach, and it has been consistently concluded that teaching through scientific inquiry represents a core tool for promoting scientific understanding (Blanchard et al., 2009; Romberg et al., 2005). While the term scientific inquiry is dominating reform-oriented literature, there is still some confusion about its exact role in science teaching (Abrams, Southerland, & Evans, 2007), and how to communicate it to K-12 students. This explains why elementary teachers often feel unprepared and uncomfortable teaching science content through scientific inquiry, as many have not had opportunities to develop the pedagogy to teach science. PCK is defined as the knowledge of the representations, analogies, and strategies useful for teaching a particular topic, as well as knowledge of students' ideas about that topic (Lee & Luft, 2008; Shulman, 1986).

Adequate SCK facilitates the planning and implementation of an effective inquiry lesson as it helps teachers respond effectively to questions, increases a teacher's comfort level and flexibility to deviate from the lesson plan when leading discussions, and provides a teacher with examples and explanations that connect with prior knowledge and ground student investigations in real life experiences (Luera et al., 2005). Without SCK, instructional representations and analogies provided in curriculum materials may be misunderstood and misused in ways that render them scientifically inappropriate for the concepts at hand, ultimately making scientific inquiry inauthentic and unlikely to achieve (Davis & Petish, 2005). There is evidence that a relationship between type of SCK and the ability to design an inquiry lesson exists. Preservice elementary teachers who had completed one or more inquiry courses were more competent in writing inquiry lessons when compared to others who had not, indicating that the opportunity to personally experience inquiry can lead to an improved ability to plan to teach an inquiry-based science lesson (Luera et al., 2005).

Elementary Teacher Preparation in Science

Given the recommendations of science reform documents over the past two decades, it would seem that teacher preparation programs would reflect these changes. In reality, elementary teacher preparation programs still largely consist of traditional class formats—a small number of lecture-based science courses that offer little opportunity for authentic inquiry, individual experimentation and "hands-on" learning—that fail to lead students to the conceptual understanding that sets the stage for later teaching inquiry-based science (Nowicki et al., 2012). According to the 2012 *National Survey of Science and Mathematics Education,* very few elementary science teachers have college or graduate degrees in science or science education. Instead, most have had formal preparation for teaching toward a teacher credential as part of their undergraduate program. The majority of elementary science teachers have taken college coursework in life science, but few have taken college courses in chemistry or physics, although they need to know how to teach content in all science subjects (Trygstad, 2013). The few science courses that preservice teachers take rarely emphasize reflection on scientific knowledge, and active participation in science is rare (Michaels et al., 2008). A study found that even preservice teachers who completed advanced teacher education requirements in science still did not have the coherent view that scientists have about different concepts in life and physical science (Rice & Kaya, 2012). Hence, requiring preservice teachers to take a larger number of science courses does not necessarily lead to stronger content knowledge and improved teaching.

In general, teacher education programs focus on the pedagogy of science rather than science content (Abd-El-Khalick & BouJaoude, 1997; Nowicki et al., 2012), which seems appropriate given that the time available for teacher preparation in science is extremely limited relative to the vast amount of information that must be conveyed (Appleton, 2006). Due to this, science methods courses at the elementary level focus on inquiry-based pedagogy but not necessarily on science content—an inherently flawed approach, since pedagogy is dependent on content knowledge (McConnell, Parker, & Eberhardt, 2013). This can cause elementary preservice teachers to "enthusiastically embrace 'hands-on' inquiry science pedagogy as a method of engaging students… without also conveying accurate science content knowledge" (Nowicki et al., 2012, p. 1136).

A feasible solution seems to lie within reform-based science methods courses that heavily incorporate science content, are active, learner-centered, and are inquiry-based (Adamson et al., 2003). A useful way to approach the preparation of elementary science teachers is to "provide experiences that challenge their conceptions regarding science as well as the teaching and learning of science" (Dana, Campbell, & Lunetta, 1997, p. 424).

In response to these issues, we have designed our science methods course to target SCK and PCK by incorporating a modified version of Bybee's 5E Instructional Model (Bybee, 1997) and Levels of Inquiry (Abrams et al., 2007; Blanchard et al., 2009) in order to more effectively prepare elementary preservice teachers to teach science. The analysis of this study focuses on these teachers' (substantive) SCK as measured by a content test.

Study Context and Participants

The PreK-4 Education Program

The current study was conducted at a midsized private university in the Northeastern United States. The PreK-4 (early childhood) education program at this institution consists of 129 credits of courses and experiences organized into three major areas of study: university core/general education (36 credits), foundations of education (36 credits), and professional preparation (57 credits). The majority of the general education and foundations courses are completed in the first 2 years of study. Of the 129 credits, 6 credits (2 courses) are in science, and students can choose any one course from basic chemistry, physics, or physical science and any one course from biology, earth science, or energy and the environment. The science content courses can be taken during the freshman or sophomore year. During their junior year, students take four credits of science content knowledge and pedagogy, which is the equivalent of a teaching elementary science methods course.

The Elementary Science Methods Course

The first author taught the elementary science methods course in which the participants were enrolled. This course contributes four credit hours to a larger 12-credit "block," which also includes social studies methods, special education, and instructional technology. The course met twice a week for 3 h blocks for 14 weeks of the semester, the remaining 3 weeks were reserved for peer teaching sessions. The course was designed to help preservice teachers develop: (1) a theoretical framework for teaching science through inquiry at the PreK-4 level based on a modified version of the 5E Instructional Model and Levels of Inquiry, (2) a repertoire of inquiry-based methods for teaching science to PreK-4 students, and (3) a deeper understanding of science content used to model inquiry-based methods. Cultural, linguistic, as well as the NOS elements were embedded throughout the course, although not in all lessons. The lesson described in this paper did not explicitly address these elements. The instructor emphasized that the science content covered represented snapshots to model inquiry-based teaching strategies, and that it was impossible to cover all science content a PreK-4 teacher is expected to teach in one semester.

Lessons were designed and implemented according to Bybee's 5E instructional model, to include components of engagement, exploration, explanation, elaboration, and evaluation (Bybee, 1997). However, based on recent results from the *2012 National Survey of Science and Mathematics Education* (Trygstad, 2013), the 5E Instructional Model was augmented or modified in several ways. We emphasized that explanation needs to be conducted by the students and not by the teacher, which was motivated by many elementary teachers' belief that teachers should explain an idea to students before they consider evidence for that idea. We showed students how to achieve this by modeling questioning and scientific reasoning throughout the lessons. We furthermore explicitly avoided presenting content prior to activities, and instead allowed students to discover the content through the exploration, extension, and explanation, as the lesson progressed. This was motivated by many teachers' belief that hands-on activities should be used primarily to reinforce ideas that the students have already learned. We defined and discussed science vocabulary as the lesson progressed, instead of in the beginning of the lesson, as most elementary teachers believe that students should be given definitions for new vocabulary at the beginning of instruction. Finally, we found value in altering the 5E Instructional Model by: (1) alternating the sequence of Es where appropriate (e.g., when a real world connection as the extension made sense to discuss prior to exploration); (2) embedding explanation into all other Es (e.g., students were encouraged to explain during engagement, exploration, extension, and evaluation); and (3) providing multiple examples for each E during a single lesson (e.g., two or three activities for exploration). We believe that these changes can help improve preservice teachers' SCK, which can in turn help with inquiry-based pedagogy. Some lessons lasted more than one class period, and some class periods were filled with logistical issues or field discussions.

Preservice teachers were engaged in about 12 inquiry-based in-class activities. These activities were content-based explorations designed to help them experience a variety of inquiry-based teaching methods and reinforce their understanding of selected science concepts, as prescribed by state standards (see Table 1). In addition to a modified version of Bybee's 5E Instructional Model, lessons were designed to meet various levels of inquiry, ranging from Level 1–Level 3 (Abrams et al., 2007; Blanchard et al., 2009). A Level 1 lesson allowed students to interpret the results of an experiment, but questions and experimental design were designated by the instructor. A Level 2 lesson allowed students to design their experiment and interpret the results, but the instructor asked the questions. A Level 3 lesson allowed the students to perform all three steps.

A modeled lesson typically began with an engagement component related to the science content (e.g., one or a combination of puzzles, questions, current events, YouTube videos, or brief activities). This was then followed by one or more opportunities for student exploration (during which students generally performed one or more hands-on/minds-on experiments), student extension/elaboration (students related the concepts of the lesson to the real world/big picture), explanation, and evaluation. Depending on the lesson, these components often deviated from the traditional 5E Instructional Model by varying in order and frequency, as described above. All topics in Table 1 were covered in a similar fashion, but due to space limitations, we chose to present a detailed description of one of the lessons on electrical circuits, as this topic is known to be particularly challenging for both students and adults (Aschbacher & Alonzo, 2006).

Electricity and electrical circuits are heavily tested topics on the state's accountability test at grade 4. The preservice teachers spent a 3 h block on this topic. A vocabulary word wall was written on the board, and science terms were crossed off as their definitions, meaning, and application were discussed. As the *engagement* component, the instructor opened the lesson by asking pairs of students to take apart a flashlight and discuss how they thought a flashlight works. This

Table 1 Science topics covered during the methods course

Content area	Examples of concepts covered		
Earth science	Biomes	Oil spills	Renewable and nonrenewable energy sources
Life science	Animal and plant adaptations	Body systems	Inherited and learned traits
Physical science	Electrical circuits	Conductors, insulators and magnetism	Sound
Nature of science	Embedded	Embedded	Embedded

occurred to activate prior knowledge on energy conversions and electron flow, during which the instructor asked open-ended questions and encouraged scientific reasoning, therefore embedding *explanation* into the *engagement* component. Taking apart the flashlight also represented a small *exploration* activity as part of the *engagement*. The main *exploration* component consisted of two activities. During the first activity, groups of four students were given kits including batteries, battery holders, light bulbs, and wires and were allowed a few minutes to find a way to make the light bulb go on without any instruction. They then shared their results by reporting to the class verbally or by drawing their circuit on the whiteboard or SMART board, *explaining* how they reached their conclusions along the way. During the second activity, the students followed a guided handout to build a series and a parallel circuit. Questions in the handout asked for predictions (e.g., "What do you think would happen if you removed one of the light bulbs?" or "What do you think would happen if you added another battery?"), as well as several "why" questions (e.g., "Why do you think the other light bulb stayed on?"). The *explanation* component was embedded throughout *exploration*, as students reasoned during the first activity and answered guided questions during the second. The *extension* component, intended for the students to make connections of the content to the real world and the big picture occurred in two instances, and in this case, following the *exploration* component. In one instance, the instructor turned off the classroom lights and asked the students to *explain* why the lights in the classroom next door did not go out as well. In another instance, the instructor plugged in a set of holiday lights and unscrewed one light bulb. The students were asked to *explain* which type of electrical circuit was present and why. The main *evaluation* component occurred when students were asked to "act out" a series and a parallel circuit, but *evaluation* took place formally (via responses on the handouts) and informally (via classroom discussion) embedded throughout the various components of the lesson.

Setting and Participants

Participants included 19 students (18 females and 1 male), ranging from ages 21–23. All were enrolled as juniors in a Bachelor of Science (B.S.) degree program in PreK-4 (early childhood) education. All 19 participants completed the science methods course requirements, the science pretest and posttest, as well as all other course assignments. During their freshman and sophomore years, the students completed two university core courses in biology, chemistry, earth science or physics, as required by the program. All students completed the biology core course, and in addition to the biology option, 16 completed the earth science option. Only three students completed the chemistry core courses and none completed the physics option. No students had completed other formal coursework in science or had been exposed to higher level science courses during their undergraduate years.

Research Procedures

Data Collection

A science knowledge test was administered to the students prior to beginning the course and after completing the course. The test took about 45 min to complete and included multiple choice, short answer, and extended response items. The science knowledge test was used to assess whether the students' SCK changed after participating in a science methods course, which strategically incorporated science content. All 19 students completed both the pretest and the posttest.

Science Knowledge Test

The test was constructed to match the topics assessed on the grade 4 state standardized science test, with the general topics including earth science, life science, physical science, and NOS. Publicly released items from the National Assessment of Educational Progress (NAEP), Third International Mathematics and Science Study (TIMSS), Pennsylvania System of School Assessment (PSSA), and Florida Comprehensive Assessment Test (FCAT) were considered. The test questions are included in the Appendix.

During test development, a science content expert and a methodologist reviewed the content of the items and provided recommendations concerning the alignment of each item with the content specifications of the test. Based on the content review recommendations, items were revised and/or removed and additional items were added to meet the content specifications. The process was guided by item difficulty of high, medium, and low (according to Webb on "Depth of Knowledge", 1999). Over 200 items were reviewed, and an initial pool of 53 items that reflected the content covered was considered. From this pool, 30 items that met the specifications were selected for the final test version. Table 2 presents the item specifications for the final science knowledge test, along with noting which questions were short answer or extended response. It should be noted that no items of high difficulty on the NOS could be located from the item sources. The final test was piloted with six undergraduate students (juniors and seniors) who were able to complete the test in

Table 2 Test item specifications for science knowledge test design

Topics	Difficulty			Total
	Low	Moderate	High	
Earth science	2, 22	7[a], 13, 26[a]	18[a]	6
Life science	1, 19	4, 5[a], 11, 12[a], 27, 29	15[b], 21	10
Physical science	6, 25	3, 9, 14[a], 16, 17, 23[a]	28[a], 30[a]	10
Nature of science	10	8, 20[a], 24[b]	–	4
Total	7	18	5	30

[a] Short response

[b] Extended response

<40 min and minor feedback regarding the formatting of the test was noted; there were no major issues reported with the items or test format.

The test consisted of 30 items and was worth a total of 41 points. The test consisted of 7 low difficulty, 18 medium difficulty, and 5 high difficulty items. There were 18 multiple choice questions and 12 short or extended response questions. There were 11 NAEP items, 15 TIMSS items, 3 PSSA items and 1 FCAT item.

Data Analysis

First, the reliability of the scores on the science test was examined using Cronbach's α. Nunnally and Bernstein (1994) note that measures with an α of 0.70 or above are considered reliable, while some authors suggest that values starting at 0.67 are acceptable (Cohen, Marion, & Morrison, 2008).

Next, the descriptive statistics for the pretest, posttest, and gain science test scores were examined, and a repeated measures one way analysis of variance (ANOVA) was conducted to determine if the change in scores from pretest to posttest was statistically significant (Research Question 1). For the purpose of this research p values <.05 were considered statistically significant. In addition, the partial eta squared measure of effect size, which is a measure of the variance accounted for, was computed to determine the effect size of the gain. The partial eta squared can be interpreted as values of <0.09 as having a small effect, between 0.09 and 0.25 as having a medium effect, and >0.25 as having a large effect (Cohen, 1988).

Finally, individual items were examined to determine on which test items growth occurred (Research Question 2). This provides insight into the types of items and on which topics science content knowledge improved. On short or extended response items that demonstrated growth, examples of responses at pretest and posttest were provided in order to illustrate how preservice teachers' scientific understanding progressed after exposure to both content and pedagogy instruction.

Results

Science Test Scores

The pretest scores had a Cronbach's α of 0.71, which indicates acceptable reliability, and the posttest scores had a Cronbach's α of 0.68, which is just below the threshold for acceptable reliability. The lower scores, especially at posttest, were due to some items being too easy and therefore not contributing information to the overall science knowledge of respondents. For example, on the posttest all students answered questions 2, 6, and 19 correctly, thus there was no variability.

The descriptive statistics for the pretest, posttest, and gain science test scores are presented in Table 3. The mean score for all students who took the pretest was 27.21 ($SD = 5.12$), which is equivalent to 66.37 % correct, and for the posttest the mean was 31.74 ($SD = 4.33$), which is equivalent to 77.41 % correct. The gain score was computed for students who took both the pre and post science tests ($n = 19$); the mean gain score for all students was 4.53 ($SD = 2.32$), which is equivalent to

Table 3 Descriptive statistics for science knowledge test

	N	Minimum	Maximum	Mean	SD
Pre	19	13	35	27.21	5.12
Post	19	22	39	31.74	4.33
Gain	19	−1	9	4.53	2.32

11.05 % correct. Both the mean scores at pretest and posttest had a normal distribution.

The ANOVA indicated a statistically significant difference between pretest and posttest, ($F_{(1,18)} = 72.43$, $p < .01$, $\eta_p^2 = 0.80$). The partial eta square measure of effect size was 0.80, which is considered a large effect (see Table 4).

Questions Demonstrating Growth

Multiple Choice

Table 5 displays the percent of students answering each multiple choice question correct at pretest and posttest. Note that the difficulty level of the items was assigned during the test development based on the responses of other samples to the publicly released items. Thus, for example, Q8 was labeled at a medium difficulty level, yet most of the sample answered this question correctly at pretest (89.5 %) and posttest (94.7 %). Most of the low difficulty items (Q1, Q2, Q6, Q10, Q19, Q22, Q25) did not display notable growth. All respondents correctly answered both Q6 and Q19 at pretest and posttest, and Q2 was answered correctly by all respondents at posttest. Thus, it seems that the students tested were already familiar with much of the low level science content. However, there was growth in some areas of moderate and high difficulty science content. Some of these items showed no growth (Q3, Q9, Q13, Q16), one showed little growth (Q11), yet many showed considerable growth (Q4, Q17, Q21, Q27, Q29).

Short and Extended Response

Table 6 displays the percent of students receiving each point a category allowed for each short or extended response item on the test. All short and extended response

Table 4 Repeated measures ANOVA for pretest and posttest scores

Source	*SS*	*df*	*MS*	*F*	*p*	η_p^2
Time	194.63	1	194.63	72.43	<.001**	0.80
Error	48.37	17	2.69			
Subjects	760.47	1	42.25			
Total	1,003.47	19				

The maximum possible score was 41 points

Table 5 Multiple choice questions percent (%) correct

Item	Benchmark	Topic	Difficulty	Pre % correct	Post % correct
Q1	Life science	Genetics	Low	89.5	94.7
Q2	Earth science	Biomes	Low	94.7	100.0
Q3	Physical science	Conductors	Moderate	63.2	63.2
Q4	Life science	Adaptations	Moderate	63.2	84.2
Q6	Physical science	Sound	Low	100.0	100.0
Q8	Nature of science	Measurement	Moderate	89.5	94.7
Q9	Physical science	Circuits	High	52.6	47.4
Q10	Nature of science	Experimental setup	Low	89.5	94.7
Q11	Life science	Body systems	Moderate	78.9	84.2
Q13	Earth science	Biomes	Moderate	73.7	68.4
Q16	Physical science	Sound	Moderate	84.2	84.2
Q17	Physical science	Circuits	Moderate	36.8	63.2
Q19	Life science	Biomes	Low	100.0	100.0
Q21	Life science	Body systems	High	15.8	36.8
Q22	Earth system	Resources	Low	68.4	68.4
Q25	Physical science	Electricity	Low	63.2	73.7
Q27	Life science	Electricity	Moderate	57.9	73.7
Q29	Life science	Adaptation	Moderate	63.2	89.5

Eighteen out of 30 test items were multiple choice

items were of moderate or high difficulty. Some items showed no growth (Q5, Q20, Q24), one showed little growth (Q12), yet many showed considerable growth (Q7, Q14, Q15, Q18, Q23, Q26, Q28, Q30). Based on these questions, it appears that students could not always write meaningful explanations to the questions at pretest, yet at posttest had developed the reasoning and explanations to respond accurately to these types of questions.

In order to demonstrate how students' understanding of science concepts progressed through the course, below, we provide selected examples of student responses on the pretest and posttest. Question 7 is a public-release item from TIMSS, which reads: "On a river near a town the government decided to build a dam for electricity and irrigation purposes. Write down one effect the dam could have on wildlife (animals or plants)." According to the TIMSS rubric, a student is awarded 0 points for no response or an incorrect response, and 1 point for a complete response, which indicated a correct response that included a specific effect on wildlife (positive or negative) due to the dam. Vague or general responses that state only plants/animals will die (or similar) with no specific effect given are scored as incorrect. On the pretest in our research, 63.2 % gave correct responses, and on the posttest, 89.5 % gave correct responses. The following responses indicate students' enhanced understanding at the end of the course compared to the beginning of the course. In addition, it is apparent that spelling and terminology became clearer at posttest.

Table 6 Percent (%) in each point category for short and extended response questions

Item	Benchmark	Topic	Difficulty		Pre %	Post %
Q5	Life science	Body systems	Moderate	0 = 0 points received	5.3	0.0
				1 = 1 points received	21.1	31.6
				2 = 2 points received	73.7	68.4
Q7	Earth science	Pollution	Moderate	0 = 0 points received	36.8	10.5
				1 = 1 points received	63.2	89.5
Q12	Life science	Genetics	Moderate	0 = 0 points received	10.5	5.3
				1 = 1 points received	21.1	21.1
				2 = 2 points received	68.4	73.7
Q14	Physical science	Magnetism	Moderate	0 = 0 points received	73.7	57.9
				1 = 1 points received	26.3	42.1
Q15	Life science	Adaptations	High	0 = 0 points received	10.5	5.3
				1 = 1 points received	36.8	10.5
				2 = 2 points received	52.6	84.2
Q18	Earth science	Pollution	Moderate	0 = 0 points received	0.0	0.0
				1 = 1 points received	5.3	0.0
				2 = 2 points received	10.5	10.5
				3 = 3 points received	42.1	21.1
				4 = 4 points received	42.1	68.4
Q20	Nature of science	Interpret data	Moderate	0 = 0 points received	15.8	15.8
				1 = 1 points received	63.2	73.7
				2 = 2 points received	21.1	10.5
Q23	Physical science	Sound	Moderate	0 = 0 points received	31.6	5.3
				1 = 1 points received	15.8	10.5
				2 = 2 points received	52.6	84.2
Q24	Nature of science	Experimental setup	Moderate	0 = 0 points received	21.1	10.5
				1 = 1 points received	0.0	0.0
				2 = 2 points received	57.9	63.2
				3 = 3 points received	21.1	26.3
Q26	Earth science	Oil spill	Moderate	0 = 0 points received	78.9	52.6
				1 = 1 points received	21.1	47.4
Q28	Physical science	Electricity	High	0 = 0 points received	78.9	21.1
				1 = 1 point received	21.1	78.9
Q30	Physical science	Sound	High	0 = 0 points received	5.3	10.5
				1 = 1 points received	78.9	36.8
				2 = 2 points received	15.8	52.6

Example 1

Pre response Could effect animal habitats and populations of animals in certain areas (0 points).

Post response The dam could interrupt habitats and block homes of animals like fish and beavers, plants will also be effected (1 point).

Example 2
Pre response It could collapse and kill the animals (0 points).
Post response This could impose on their territory and the animals may become upset and have to relocate (1 point).

Question 23 is a public-release item from NAEP which reads: "Lightning and thunder happen at the same time, but you see the lightning before you hear the thunder, Explain why this is so." The respondent received 2 points for stating that although thunder and lightning occur at the same time, light travels faster than sound; 1 point for a response that addresses speed and uses terminology such as thunder for sound and lightning for light, or makes a general statement about speed but does not tell which is faster; and 0 points if the student response does not relate the speeds at which light and sound travel. On this item, at pretest 31.6 % received 0 points; 15.8 % received 1 point; and 52.6 % received 2 points. At posttest, 5.3 % received 0 points, 10.5 % received 1 point; and 84.2 % received 2 points. The following responses indicate students' enhanced understanding at the end of the course compared to the beginning of the course. In the first example, there is a misconception at pretest, which changed at posttest. In the second example, the student clarifies the response at posttest to state which travels faster, thus earning a higher score according to the rubric.

Example 1
Pre response Thunder is farther away (0 points).
Post response Light travels faster than sound (2 points).

Example 2
Pre response Because light and sound waves move at different times (1 point).
Post response: They happen at the same time, it is just that light speed is faster than sound speed (2 points).

Question 28 is a public-release item from TIMSS, which reads: "Homes are wired for electricity using parallel circuits not series circuits. What is the advantage of using parallel circuits in a home?" The respondent received 1 point for a response that mentions either: (1) a parallel circuit has more than one pathway for the current to flow through, and if one pathway is switched off the other pathways still work, or (2) if an appliance does not work (or the fuse breaks), the other appliances can still be used and 0 points for an incorrect response. On this item at pretest, 21.1 % received 1 point and at posttest, 78.9 % received 1 point. The following responses indicate students' enhanced understanding at the end of the course compared to the beginning of the course. It is apparent that at pretest, there was not a clear sense of why parallel circuits are used in a home, while at posttest, this concept was understood and students were able to explain why.

Example 1
Pre response May be safer because of the way wires are run (0 points).
Post response When you go to turn off a light in one room, you wouldn't be turning off the lights in the whole house (1 point).

Example 2
Pre response It cuts down on the electric billx (0 points).
Post response You can shut a light off in one room and it won't shut all your lights off in your whole house (1 point).

Example 3
Pre response There are less opportunities for the circuits to break/not work (0 points).
Post response Because if a circuit is broken in a parallel circuit, not all the lights in the house will go out (1 point).

Discussion and Implications

This study examined preservice elementary teachers' development of (substantive) SCK within the context of an elementary science methods course. A project-developed science knowledge test was administered to 19 preservice elementary teachers at the beginning and the end of their science methods course, before and after science content was covered through modeled inquiry-based pedagogy. We present conclusions drawing upon the results, as well as implications for future research.

Discussion

Our first research question asked how preservice elementary teachers' SCK improved from pretest to posttest, as measured by a knowledge test. Descriptive statistics indicate a statistically significant change in overall science content knowledge, with a large effect size. We believe that the way the course was taught—including snapshots of science content modeled through a modified version of Bybee's 5E Instructional Model—contributed to this important result. While we are cautious to claim causality for our study, we are comfortable asserting that the design and implementation of our elementary science methods course and the improved pretest/posttest scores are no accident. Our preservice teacher sample was not enrolled in other science courses or science methods courses emphasizing science content during the presented semester, which could have contributed to the improved test scores. The students' past science courses were mainly taken in the life sciences, yet the test scores improved across all science content areas, which speaks to the effectiveness of our course. Based on these results, we conclude that the participating preservice elementary teachers strengthened and deepened their science content knowledge upon completing the course.

Our second research question asked on which test items the preservice teachers displayed the most notable growth from pretest to posttest. There are three findings to this question. The first finding is that test items of low difficulty, which were all multiple choice, displayed no growth. This leads us to conclude that preservice elementary teachers have some science content knowledge, may it be from prior experience in school or every day science, but we believe it is superficial. Several moderately difficult test items did show growth, however. For example, two items on adaptations showed growth, and two items on electricity showed growth. These results indicate that preservice teachers strengthened their content knowledge on these topics upon them being covered in the course and potentially challenged their previously existing misconceptions.

Our second finding (Research Question 2) is that most short and extended response items displayed growth. All high difficulty and most moderate difficulty test items displayed growth, which strongly indicates that when preservice teachers were asked to explain scientific phenomena prior to covering the content in the course, they did not possess adequate science content knowledge to do so. However, upon covering the content, they were able to articulate meaningful answers to the questions. It is important to note that short and extended response test items require the test taker to write out and explain the answer, instead of having an answer to choose from, as in multiple choice questions. This signifies that the preservice teachers developed deep rather than superficial understanding of the topics. It is also possible that this improvement may be related to the high emphasis of *explanation* as embedded throughout the 5E Instructional Model during the methods course. Since preservice teachers were not only asked to explain during the designated explanation portion, but during engagement, exploration, extension, and evaluation, it appears that they internalized science concepts through constantly having to explain their reasoning.

Finally, growth was generally visible across all three content areas of life, physical, and earth science. We noticed that improvement was linked to test item difficulty and not necessarily to content area. Had improvement mainly been observed in chemical and physical sciences (courses preservice teachers had not taken prior to the methods course), but consistent high scores from pretest to posttest in life and earth sciences, the growth could have been attributed to prior exposure to the content. Instead, this result suggests that preservice elementary teachers, as generalists, may know “a little bit of everything,” as indicated by their performance on the low difficulty items, but during the methods course added depth to their shallow science content knowledge, as indicated by their performance on the moderate and high difficulty items.

We are aware that our study has limitations. We were limited to a small sample size of 19, as that was the number of students enrolled in the science methods course. A control group was also not feasible, as this was the only methods course offered during the academic year data were collected. The Cronbach’s α at posttest was just below the threshold for acceptable reliability. This is likely due to some items being too easy and therefore not contributing information to the overall science knowledge of respondents.

Implications

A major motivation of our study was the status of elementary teachers’ SCK and how inadequate SCK can negatively impact elementary teachers’ teaching through inquiry and in turn student achievement in science (Darling-Hammond & Youngs, 2002; Krall et al., 2009; Wright et al., 1997). Our results indicate that preservice teachers developed “an inch deep” science knowledge that we hope is more likely to lead to effective science teaching than the typically “mile wide” science knowledge of elementary teachers. The findings of our study make two important contributions to the field of science education. First, it is our responsibility as science educators to re-focus our research on SCK. While PCK is certainly an area that needs continued attention, we maintain that science PCK is not attainable without solid SCK as a foundational component. Second, we believe that is necessary to revisit widely accepted instructional models such as the 5E Instructional Model by alternating the sequence of Es where appropriate, by embedding the explanation component into all other Es, and by providing multiple examples for each E during a single lesson. While our study provides some initial insights into how altering this model could affect SCK, larger scale studies are necessary to establish further impacts of these (and other) alterations.

If there is a direct correlation between student achievement and teachers’ preparedness to teach science (Darling-Hammond & Youngs, 2002; Krall et al., 2009; Wright et al., 1997), we assert that it is imperative for preservice elementary teachers to build deep and complex understanding of science content in order to teach it to their students through reform-based authentic inquiry. While these teachers may possess some science content knowledge, we agree that it is generally not sufficient to teach standards-based rigorous science content, even at the elementary level (Burgoon et al., 2011; Dawkins et al., 2008; Kikas, 2004; Krall et al., 2009; Leite et al., 2007). Instead, our study suggests that any preexisting science content knowledge must be solidified and deepened—instead of assuming it preexists (Weiss et al., 2001)—and that potential misconceptions must be addressed (Bulunuz & Jarrett, 2009; Burgoon et al., 2011; Bursal, 2012; Rice & Kaya, 2012). These rather ambitious goals are not achievable through traditional teaching methods such as lecturing. These goals are more likely attainable through the implementation of inquiry-based methodology, where preservice teachers are able to internalize the scientific content by means of experiencing authentic scientific inquiry.

If teachers are expected to teach using authentic inquiry (Davis, 2004), it is our responsibility as teacher educators to engage preservice elementary teachers in authentic scientific inquiry in order to provide them with a strong foundation of SCK (AAAS, 1989, 1993; Krajcik & Sutherland, 2010; Michaels et al., 2008; Nowicki et al., 2012; NRC, 1996, 2000; Osborne, 2010). Elementary science methods courses should include science content, yet covering it superficially does not suffice. Teaching science content and science pedagogy as two separate entities—one as a lecture course and the other as a methods course that focuses on pedagogy alone—is a flawed approach to strengthening preservice teachers’ science content knowledge and ultimately how they teach when they enter the teaching profession.

While our study provides insight into important issues, there are additional areas that need to be explored. We believe that strong substantive SCK is a prerequisite to teaching science through inquiry, and we measured that through a science test. However, it is also critical to know how long preservice elementary teachers retain the learned science content knowledge, as in other contexts it has been shown that over half of this knowledge is retained after 1 year, with a further decrease to slightly below half in the next year (Custers, 2010). It is also important to know how elementary preservice teachers develop syntactic SCK and how this is related to substantive SCK. Additional data sources investigating teachers' beliefs and reflections could contribute to this research. Finally, it is essential to know to what extent preservice elementary teachers transfer content knowledge and inquiry-based practices into student teaching and finally into their appointment as teachers. To explore this, further studies that investigate how teachers incorporate science content into their pedagogy need to be conducted (Nowicki et al., 2012).

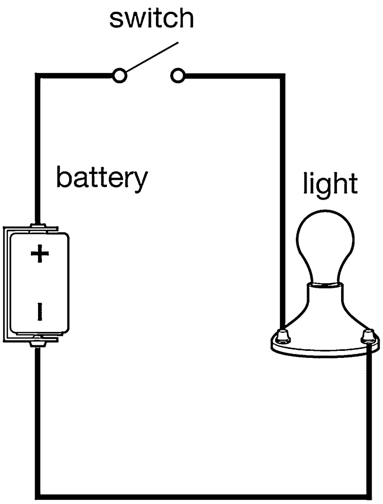
Appendix

Question 4

> A population of mice, some with light-colored fur and some with dark-colored fur, is introduced into a field with dark soil. A few generations later, the majority of the mice have dark-colored fur. Which hypothesis is the most consistent with the observed changes in the physical appearances of the mice?

A. Light-colored mice can run faster.
B. Dark-colored mice have fewer offspring.
C. Light-colored mice have changed color over generations.
D. Dark-colored mice are better able to hide from their predators.*

Question 17



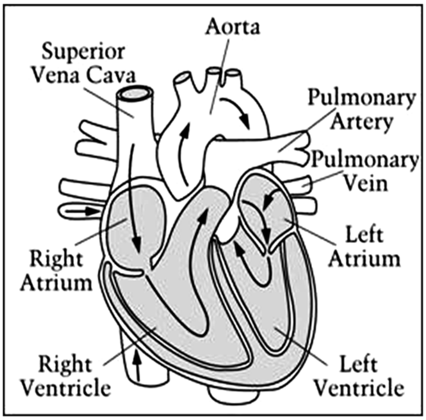
Which description **best** describes this circuit?

A. Electric current is running through this series circuit.
B. Electric current is not running through this series circuit.*
C. Electric current is running through this parallel circuit.
D. Electric current is not running through this parallel circuit.

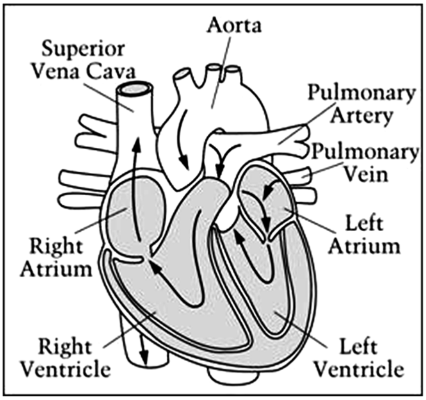
Question 21

Each diagram below shows the same front view of a human heart. Which diagram has arrows that correctly show the path of blood flow through the heart and the blood vessels leading to and from the heart?

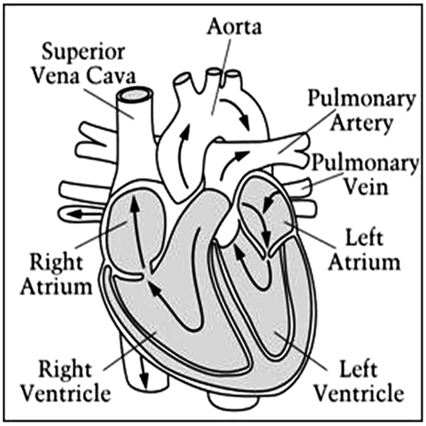
A*



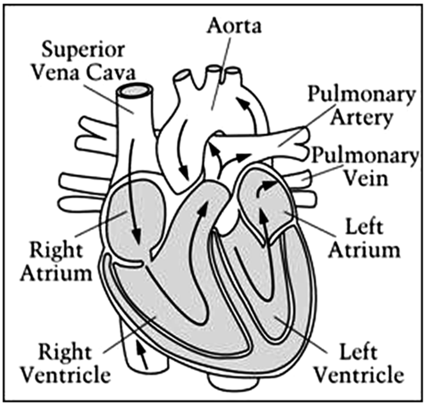
B



C

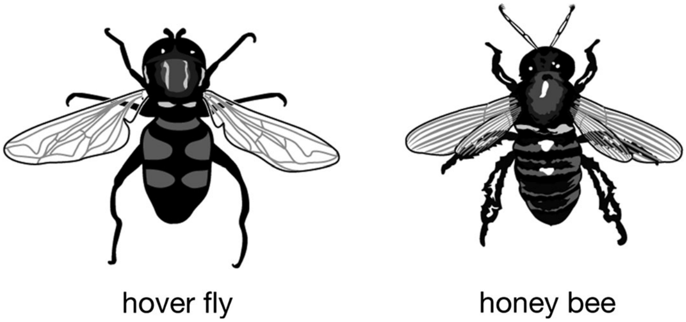


D



Question 29

A hover fly looks like a honey bee. Which statement **best** explains how this adaptation helps the hover fly survive?



A. Looking like a honey bee keeps other animals away from the hover fly's food.
B. Looking like a honey bee allows the hover fly to collect more pollen.
C. Looking like a honey bee allows the hover fly to blend with its environment.
D. Looking like a honey bee keeps some predators from trying to eat the hover fly.*

* Indicates the correct answer.

References

Abd-El-Khalick, F., & BouJaoude, S. (1997). An exploratory study of the knowledge base for science teaching. *Journal of Research in Science Teaching, 34*, 673–699.

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1105–1149). Mahwah, NJ: Erlbaum.

Abrams, E., Southerland, S. A., & Evans, C. A. (2007). Inquiry in the classroom: Necessary components of a useful definition. In E. Abrams, S. A. Southerland, & P. Silva (Eds.), *Inquiry in the science classroom: Realities and opportunities*. Greenwich, CT: Information Age.

Adamson, K., Santau, A. O., & Lee. O. (2013). The impact of professional development on elementary teachers' strategies for teaching science with diverse student groups in urban elementary schools. *Journal of Science Teacher Education*, *24*, 553–571.

Adamson, S. L., Banks, D., Burtch, M., Cox, F. III, Judson, E., Turley, J. B., … & Lawson, A. E. (2003). Reformed undergraduate instruction and its subsequent impact on secondary school teaching practice and student achievement. *Journal of Research in Science Teaching, 40*, 939–957.

Akerson, V. L. (2005). How do elementary teachers compensate for incomplete science content knowledge? *Research in Science Education, 35*, 245–268.

American Association for the Advancement of Science. (1989). *Science for all Americans*. New York, NY: Oxford University.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York, NY: Oxford University.

Anderson, D., & Clark, M. (2012). Development of syntactic subject matter knowledge and pedagogical content knowledge for science by a generalist elementary teacher. *Teachers and Teaching: Theory and Practice, 18*, 315–330.

Appleton, K. (2006). *Elementary science teacher education: International perspectives on contemporary issues and practice*. Mahwah, NJ: Erlbaum.

Aschbacher, P., & Alonzo, A. (2006). Examining the utility of elementary science notebooks for formative assessment purposes. *Educational Assessment, 11*, 179–203.

Blanchard, M., Southerland, S. A., & Granger, D. E. (2009). No silver bullet for inquiry: Making sense of teacher change following inquiry-based research experience for teachers. *Science Education, 93*, 322–360.

Bulunuz, N., & Jarrett, O. S. (2009). Understanding of earth and space science concepts: Strategies for concept-building in elementary teacher preparation. *School Science and Mathematics, 109*, 276–286.

Burgoon, J. N., Heddle, M. L., & Duran, E. (2011). Re-examining the similarities between teacher and student conceptions about physical science. *Journal of Science Teacher Education, 22*, 101–114.

Bursal, M. (2012). Changes in American preservice elementary teachers' efficacy beliefs and anxieties during a science methods course. *Science Education International, 23*, 40–55.

Bybee, R. W. (1997). *Achieving scientific literacy: From purposes to practices*. Portsmouth, NH: Heinemann.

Carlsen, W. S. (1987). *Why do you ask? The effects of science teacher subject-matter knowledge on teacher questioning and classroom discourse*. Paper presented at the meeting of the American Educational Research Association, Washington, DC.

Carrier, S. J. (2013). Elementary preservice teachers' science vocabulary: Knowledge and application. *Journal of Science Teacher Education, 24*, 405–425.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Mahwah, NJ: Erlbaum.

Cohen, L., Marion, L., & Morrison, K. (2008). *Research methods in education* (6th ed.). London, England: Routledge, Taylor and Francis.

Custers, E. J. F. M. (2010). Long term retention of basic science knowledge: A review study. *Advances in Health Sciences Education, 15*, 109–128.

Dana, T. M., Campbell, L. M., & Lunetta, V. N. (1997). Theoretical bases for reform of science teacher education. *The Elementary School Journal, 97*, 419–432.

Darling-Hammond, L., & Youngs, P. (2002). Defining "highly qualified teachers": What does "scientifically based research" actually tell us? *Educational Researcher, 31*(9), 13–25.

Davis, E. A. (2004). Knowledge integration in science teaching: Analysing teachers' knowledge development. *Research in Science Education, 34*, 21–53.

Davis, E. A., & Petish, D. (2005). Real-world applications and instructional representations among prospective elementary science teachers. *Journal of Science Teacher Education, 16*, 263–286.

Dawkins, K. R., Dickerson, D. L., McKinney, S. E., & Butler, S. (2008). Teaching density to middle school students: Preservice science teachers' content knowledge and pedagogical practices. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas, 82*, 21–26.

Eshach, H., & Fried, M. N. (2005). Should science be taught in early childhood? *Journal of Science Education and Technology, 14*, 315–336.

Fulp, S. L. (2002). *2000 national survey of science and mathematics education: The status of elementary school science teaching*. Retrieved from Horizon Research website: http://2000survey.horizonresearch.com/reports/elem_science.php

Gardner, D. P. (1983). *A nation at risk*. Washington, DC: Government Printing Office.

Gess-Newsome, J., Southerland, S. A., Johnston, A., & Woodbury, S. (2003). Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching. *American Educational Research Journal, 40*, 731–767.

Griffith, G., & Scharmann, L. (2008). Initial impacts of No Child Left Behind on elementary science education. *Journal of Elementary Science Education, 20*(3), 35–48.

Kennedy, M. M. (1998). Education reform and subject matter knowledge. *Journal of Research in Science Teaching, 35*, 249–263.

Kikas, E. (2004). Teachers' conceptions and misconceptions concerning three natural phenomena. *Journal of Research in Science Teaching, 41*, 432–448.

Kind, V. (2009). A conflict in your head: An exploration of trainee science teachers' subject matter knowledge development and its impact on teacher self-confidence. *International Journal of Science Education, 31*, 1529–1562.

Krajcik, J. S., & Sutherland, L. M. (2010). Supporting students in developing literacy in science. *Science, 328*, 456–459.

Krall, R., Lott, K. H., & Wymer, C. L. (2009). Inservice elementary and middle school teachers' conceptions of photosynthesis and respiration. *Journal of Science Teacher Education, 20*, 41–55.

Lee, E., & Luft, J. A. (2008). Experienced secondary science teachers' representation of pedagogical content knowledge. *International Journal of Science Education, 30*, 1343–1363.

Lee, O., Luykx, A., Buxton, C., & Shaver, A. (2007). The challenge of altering elementary school teachers' beliefs and practices regarding linguistic and cultural diversity in science instruction. *Journal of Research in Science Teaching, 44*, 1269–1291.

Leite, L., Mendoza, J., & Borsese, A. (2007). Teachers' and prospective teachers' explanations of liquid-state phenomena: A comparative study involving three European countries. *Journal of Research in Science Teaching, 44*, 349–374.

Luera, G. R., Moyer, R. H., & Everett, S. A. (2005). What type and level of science content knowledge of elementary education students affect their ability to construct an inquiry-based science lesson? *Journal of Elementary Science Education, 17*(1), 12–25.

Marx, R. W., & Harris, C. J. (2006). No Child Left Behind and science education: Opportunities, challenges, and risk. *Elementary School Journal, 106*, 455–466.

McConnell, T. J., Parker, J. M., & Eberhardt, J. (2013). Assessing teachers' science content knowledge: A strategy for assessing depth of understanding. *Journal of Science Teacher Education, 24*, 717–743.

McMurrer, J. (2007). *Choices, changes, and challenges: Curriculum and instruction in the NCLB era*. Washington, DC: Center on Education Policy.

McMurrer, J. (2008). *Instructional time in elementary schools: A closer look at changes for specific subjects*. Washington, DC: Center on Education Policy.

Michaels, S., Shouse, A. W., & Schweingruber, H. A. (2008). *Ready, set, science! Putting research to work in K-8 science classrooms*. Board on Science Education, Center for Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies.

Milner, A. R., Sondergeld, T. A., Demir, A., Johnson, C. C., & Czerniak, C. M. (2011). Elementary teachers' beliefs about teaching science and classroom practice: An examination of pre/post NCLB testing in science. *Journal of Science Teacher Education, 23*, 111–132.

National Academy of Science. (2005). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, DC: National Academy Press.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy.

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, DC: National Academy.

Newton, D. P., & Newton, L. D. (2001). Subject content knowledge and teacher talk in the primary science classroom. *European Journal of Teacher Education, 24*, 369–379.

Nilsson, P., & Van Driel, J. (2010). Teaching together and learning together: Primary science student teachers' and their mentors' joint teaching and learning in the primary classroom. *Teaching and Teacher Education, 26*, 1309–1318.

No Child Left Behind Act of 2001. (2002). Publ. no. 107–110, § 115, Stat. 1425.

Nowicki, B. L., Sullivan-Watts, B., Shim, M. K., Young, B., & Pockalny, R. (2012). Factors influencing science content accuracy in elementary inquiry science lessons. *Research in Science Education, 43*, 1135–1154.

Nunnally, J., & Bernstein, L. (1994). *Psychometric theory* (3rd ed.). New York, NY: McGraw-Hill.

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science, 328*, 463–466.

Rice, D. C. (2005). I didn't know oxygen could boil! What preservice and inservice elementary teachers' answers to "simple" science questions reveals about their subject matter knowledge. *International Journal of Science Education, 27*, 1059–1082.

Rice, D. C., & Kaya, S. (2012). Exploring relations among preservice elementary teachers' ideas about evolution, understanding of relevant science concepts, and college science coursework. *Research in Science Education, 42*, 165–179.

Romberg, T. A., Carpenter, T., & Dremock, F. (Eds.). (2005). *Understanding mathematics and science matters*. Mahwah, NJ: Erlbaum.

Sharp, J., & Hopkin, R. (2007). How prepared do you feel to teach primary science? *Primary Science Review, 100*, 5–7.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Stein, M., Larrabee, T. G., & Barman, C. R. (2008). A study of common beliefs and misconceptions in physical science. *Journal of Elementary Science Education, 20*(2), 1–11.

Supovitz, J. A., & Turner, H. M. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching, 37*, 963–980.

Trygstad, P. J. (2013). *2012 National Survey of Science and Mathematics Education: Status of elementary school science*. Chapel Hill, NC: Horizon Research.

Webb, N. (1999). *Research monograph no. 18: Alignment of science and mathematics standards and assessments in four states*. Washington, DC: CCSSO.

Weiss, I. R., Banilower, E. R., McMahon, K. C., & Smith, P. S. (2001). *Report of the 2000 National Survey of Science and Mathematics Education*. Chapel Hill, NC: Horizon Research.

Wright, S. P., Horn, S. P., & Sanders, W. L. (1997). Teacher and classroom context effects on student achievement: Implications for teacher evaluation. *Journal of Personnel Evaluation in Education, 11*, 57–67.