Impacts of Contextual and Explicit Instruction on Preservice Elementary Teachers’ Understandings of the Nature of Science

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Abstract: This mixed-methods investigation compared the relative impacts of instructional approach and context of nature of science instruction on preservice elementary teachers’ understandings. The sample consisted of 75 preservice teachers enrolled in four sections of an elementary science methods course. Independent variables included instructional approach to teaching nature of science (implicit vs. explicit) and the context of nature of science instruction (as a stand-alone topic vs. situated within instruction about global climate change and global warming). These treatments were randomly applied to the four class sections along a 2×2 matrix, permitting the comparison of outcomes for each independent variable separately and in combination to those of a control group. Data collection spanned the semester-long course and included written responses to pre- and post-treatment administrations of the VNOS-B, semi-structured interviews, and a variety of classroom artifacts. Qualitative methods were used to analyze the data with the goal of constructing profiles of participants’ understandings of the nature of science and of global climate change/global warming (GCC/GW). These profiles were compared across treatments using non-parametric statistics to assess the relative effectiveness of the four instructional approaches. Results indicated that preservice teachers who experienced explicit instruction about the nature of science made statistically significant gains in their views of nature of science regardless of whether the nature of science instruction was situated within the context of GCC/GW or as a stand-alone topic. Further, the participants who experienced explicit nature of science instruction as a stand-alone topic were able to apply their understandings of nature of science appropriately to novel situations and issues. We address the implications of these results for teaching the nature of science in teacher preparation courses. © 2010 Wiley Periodicals, Inc. J Res Sci Teach 48: 414–436, 2011

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Current science education reform efforts have placed increased emphasis on developing accurate understandings of the nature of science. Both the Benchmarks for Scientific Literacy and the National Science Education Standards portray the nature of science as a key component of scientific literacy, and present it as content to be addressed in science instruction across all grade levels. Additionally, a wide range of benefits of nature of science instruction has been advanced, from developing a better foundation for understanding traditional science content to enabling students (and the general public) to be more informed decision-makers and consumers of science (McComas, Clough, & Alamazroa, 1998). Despite the promotion of these potential benefits and the wide-spread endorsement of the science education community, research has consistently shown that K-16 students do not attain desired understandings (Duschl, 1990; Lederman, 2007). While discouraging, this state of affairs is hardly surprising given teachers’ lack of understanding (Abell & Smith, 1994; Akerson, Morrison, & McDuffie, 2006; King, 1991; Lakin & Wellington, 1994; Murcia & Schibeci, 1999; Smith & Anderson, 1999; Tsai, 2002) and the reported difficulties teachers experience in addressing the nature of science in classroom instruction (Abd-El-Khalick, Bell, & Lederman, 1998;
Early research focused attention on improving teachers’ understandings of the nature of science with the assumption that teachers’ instructional practice is substantially influenced by their conceptions of the nature of science (Lederman, 2007). While a few initial studies provided some support for this assumption (Brickhouse, 1990; Lantz & Kass, 1987), subsequent research has supported a more nuanced view of the translation of teachers’ understandings of the nature of science into instructional practice (e.g., Akerson & Abd-El-Khalick, 2003; Abd-El-Khalick et al., 1998; Hodson, 1993; Mellado, 1997; Southerland, Gess-Newsome, & Johnston, 2003; Trumbull, Scrano, & Bonney, 2006).

While teachers’ understandings of the nature of science apparently do not translate directly into instructional practice, it is also obvious that teachers cannot effectively design and teach lessons about concepts they do not understand. In other words, understanding the nature of science is a necessary, but not sufficient, condition for explicit nature of science instruction (Abd-El-Khalick et al., 1998). Further, teachers without the requisite understandings of the nature of science are likely to promote absolute views while overemphasizing vocabulary and the knowledge aspects of science (Duschl, 1988; Gess-Newsome, 1999). Thus, improving teachers’ understandings of the nature of science is an important initial step in improving the nature of science instruction that children experience in K-12 classrooms.

### Strategies for Teaching Nature of Science

Over the past four decades, three primary strategies to teaching the nature of science have emerged, including the historic, implicit, and explicit approaches (Lederman, 1998). The historic approach employs episodes from the history of science to illustrate various aspects of the nature of science. The implicit approach emphasizes doing science, under the assumption that participation in authentic scientific investigations in itself will help students develop more accurate understandings of the nature of scientific inquiry and knowledge. The explicit approach specifies that instructional goals related to the nature of science “should be planned for instead of being anticipated as a side effect or secondary product” (Akindehin, 1988, p. 73). Not to be confused with didactic instruction, the explicit approach seeks to intentionally draw students’ attention to targeted aspects of the nature of science through discussion, reflection, and specific questioning in the context of activities, investigations, historical examples, and analogies.

### Effectiveness of Explicit Instruction

In a critical review of the research on nature of science instruction, Abd-El-Khalick and Lederman (2000) concluded that explicit approaches have been more consistently effective than either historical or implicit approaches. They point to a substantial body of research indicating that explicit nature of science instruction can be effective in developing the type of understandings prescribed in science education reform documents. Much of the subsequent research has supported this conclusion (Abd-El-Khalick & Akerson, 2004; Akerson & Hanuscin, 2007; Hanuscin, Akerson, & Phillipson-Mower, 2006; Khishfe, 2008; Scharmann, Smith, James, & Jensen, 2005; Schwartz, Lederman, & Crawford, 2004).

On the other hand, a number of investigations utilizing an explicit approach to nature of science instruction have met with limited or no success (Carey, Evans, Hona, Jay, & Unger, 1989; Khishfe & Abd-El-Khalick, 2002; Leach, Hind, & Ryder, 2003; Liu & Lederman, 2002; Morrison, Raab, & Ingram, 2009; Tao, 2003). Furthermore, the majority of assessments of the effectiveness of explicit approaches have utilized single treatment case studies lacking a comparison group. Only one study has compared explicit versus implicit nature of science instruction (Khishfe & Abd-El-Khalick, 2002). While the results favored the explicit approach, student gains were not high for the participating sixth grade students in a private school in Lebanon.

Thus, although a large body of research supports the effectiveness of explicit nature of science instructional approaches, direct comparisons of the relative effectiveness of explicit versus implicit nature of science instructional approaches are lacking in the field. This gap in the research, combined with the mixed results reported in previous case studies, points to the need for assessments of the explicit approach to nature of science instruction that include a comparison group. Including preservice teacher participants in such an

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investigation would provide an important contribution to our understanding of how to improve teachers’ conceptions of the nature of science.

The Question of Context

With respect to science content, nature of science instruction may be categorized as contextualized or noncontextualized. In contextualized instruction, the nature of science is integrated within specific science content. Specific examples of such integration include embedding nature of science concepts within (a) instruction about the development of modern conceptions of the structure of the atom, (b) argumentation and debate concerning socioscientific issues, and (c) developing science process skills. When taught in a noncontextualized manner, nature of science is the primary focus of instruction and is taught through the use of activities and discussion specifically designed to promote particular aspects of the nature of science, with no direct connection to science content or process skills.

Some have voiced concern over the lack of authentic context when the nature of science is taught apart from substantial science content (Brickhouse, Dagher, Letts, & Shipman, 2000; Johnston & Southerland, 2002; Olson & Clough, 2001; Ryder, Leach, & Driver, 1999; Smith & Scharmann, 1999). These authors have cautioned that noncontextualized instruction is unlikely to engender the robust understandings of the nature of science that would serve as a foundation for addressing the nature of science in the teachers’ own science instruction. In fact, Clough (2003) asserts that much of the failure of contemporary attempts to teach nature of science relates expressly to such instruction. Because the focus of science methods courses is on the practice of teaching rather than science content, it is likely that noncontextual nature of science instruction is the norm. Certainly, the research on situated learning (e.g., Brown, Collins, & Duguid, 1989; Metz, 1998; Roth, 1995; Wells, 1999) supports a cautionary stance on students’ ability to view the nature of science as an integral component of science when taught apart from what they perceive as “real” science content.

Science educators have few empirical studies upon which to draw when considering the question of context in nature of science instruction, and these investigations have produced mixed results. Three case studies feature instructional interventions in which nature of science instruction was set in the context of science content or inquiry instruction. Solomon, Duveen, Scot, and McCarty (1992) explored the efficacy of integrating nature of science instruction within science content and historical episodes. Results of this study were mixed: The middle school student participants demonstrated gains in their understandings of only a subset of the target concepts. Khishfe and Abd-El-Khalick (2002) assessed the impact of explicit nature of science instruction situated within the context of inquiry-oriented activities on sixth-grade students’ conceptions of the nature of science. Less than half of the class demonstrated improved understandings after the 2.5-month instructional intervention. Most recently, Matkins and Bell (2007) described changes in preservice elementary teachers’ views of the nature of science after explicit nature of science instruction situated within the socioscientific issue of global climate change. Participants’ conceptions of the nature of science improved substantially and they were able to apply their nature of science conceptions to decision making about socioscientific issues.

The noncontextual approach to nature of science instruction has been assessed in three case studies, with two of these involving secondary students in summer camps. Durkee (1974) assessed the impact of explicit nature of science instruction within a summer program for talented high school students. The 6-week physics-astronomy course featured a variety of experimental projects, seminars, field trips, and readings, with nature of science instruction limited to a single discussion period per week. Results showed no significant gains in students’ understandings. Liu and Lederman (2002) assessed the impact of a summer camp focusing on scientific inquiry and the nature of science. The week-long intervention did not produce changes in the Taiwanese middle school students’ views of the nature of science. Akerson, Abd-El-Khalick, and Lederman (2000) assessed the influence of activity-based, noncontextual instruction on preservice elementary teachers’ conceptions of key aspects of the nature of science. The investigation took place in a single elementary science methods course. Contrasting with the negative results cited for the previous two investigations, the researchers reported gains in many of the participants’ understandings. However, these gains were not consistent across all of the targeted aspects of the nature of science.

Two studies have directly compared the effectiveness of contextualized and noncontextualized approaches to nature of science instruction. In the first study, the relative effectiveness of contextual versus
noncontextual nature of science instruction was compared for ninth-grade environmental science students (Khishfe & Lederman, 2006). In the second study, the effectiveness of contextual versus noncontextual nature of science instruction was compared for high school students in biology, chemistry, and environmental science (Khishfe & Lederman, 2007). Each of the three participating teachers taught two classes: one with nature of science instruction integrated within the course content, and the other with noncontextual nature of science instruction. Results of both of these studies suggest moderate improvement in students’ conceptions of the nature of science, regardless of discipline or whether nature of science instruction was taught in a contextual manner.

Taken as a whole, these eight studies paint a mixed picture of the importance of context in nature of science instruction. For the six case studies, positive results were indicated in both contextual (Matkins & Bell, 2007) and noncontextual (Akerson et al., 2000) approaches, and mixed or negative results were just as likely in either approach (Durkee, 1974; Khishfe & Abd-El-Khalick, 2002; Liu & Lederman, 2002; Solomon et al., 1992). It should be noted that these investigations used case study methodologies applied to a wide variety of student ages and abilities across diverse settings. The overall mixed results combined with the varied contexts of the six case studies makes generalized conclusions from this small body of literature problematic. The Khishfe and Lederman investigations (2006, 2007) provide direct comparisons of the contextual and noncontextual approaches. However, these studies focused only on middle and high school students. The question remains whether similar results would be obtained in more mature students, and preservice teachers in particular. Understanding how college-level students learn nature of science effectively is critical for science teacher education programs. Can the nature of science be adequately addressed in science methods courses, or should such instruction be relegated to science content courses? If the nature of science can be addressed in the science methods course, should it be set in the context of authentic science content, or can the nature of science itself be the focus of instruction?

**Situated Learning**

Lave and Wenger’s (1991) perspective on situated learning theory provides a theoretical framework for understanding connections between nature of science instruction and context. According to this theory, learning cannot be achieved separately from the context in which it occurs. The major assertions of situated learning include that understanding a concept is a result of on-going construction, knowledge must be learned in an authentic context of how it will be used, and that learning is a process of increasing participation in a community of practice (Lave & Wenger, 1991; Orgill, 2007). Thus, situated learning perspectives provide “part of a theoretical justification for ‘inquiry-based’ approaches to science teaching and learning” as learning through authentic activities is emphasized (Scott, Asoko, & Leach, 2007). Situated learning theory suggests that learners will more successfully integrate nature of science concepts into their schema when they learn about the nature of science in an authentic context. Furthermore, the previously reviewed literature concerning explicit versus implicit approaches to nature of science instruction can be viewed within the framework of situated learning. For example, implicit approaches to nature of science instruction emphasize context as being necessary and sufficient for learning. Explicit approaches, on the other hand, may or may not view authentic context as necessary to learning the nature of science. However, in either case, explicit approaches view context alone as insufficient—some form of explicit reflection must accompany authentic activities and experiences.

**Socioscientific Issues and Nature of Science**

Socioscientific issues are defined as those issues in which both social and scientific factors play a central role (Sadler, 2004), and where the collective co-existence of human beings interfaces with aspects of the natural world and often leads to questions about future human actions and behaviors. Many have suggested that socioscientific issues provide an ideal context for enhancing students’ and teachers’ understandings of the nature of science (Bentley & Fleury, 1998; Collins & Pinch, 1998; Spector, Strong, & La Porta, 1998). Integrating socioscientific issues in science instruction has the potential to empower students and better prepare them to be informed decision-makers as adults (Driver, Newton, & Osborne, 2000). Socioscientific issues provide a potentially powerful context in which teachers can integrate instruction about science.
content and the nature of science in ways that helps “students envision the connection that exists between more global issues and themselves” (Sadler, 2004). Furthermore, socioscientific issues can be presented as subunits within a typical science methods course, providing an appropriate and practical context for nature of science instruction.

In a recent investigation, the authors demonstrated the effectiveness of setting nature of science instruction in the context of a socioscientific issue taught in an elementary science methods class (Matkins & Bell, 2007). The preservice elementary teachers involved in the study made substantial gains in their understandings of the nature of science through explicit instruction closely integrated within the socioscientific issue of global warming. Furthermore, they demonstrated some ability to apply their understandings of the nature of science to decision making. However, this case study did not provide a direct comparison of the relative effectiveness of contextualized versus noncontextualized nature of science instruction. Furthermore, as indicated earlier in this literature review, the body of research on the relative effectiveness of explicit nature of science instruction remains equivocal. Thus, an investigation that provides direct comparisons of explicit and implicit instruction, both as stand-alone lessons and set within the context of a socioscientific issue, would make an important contribution to our understanding of how nature of science may best be addressed in science teacher preparation. Consequently, the present investigation seeks to assess the relative effectiveness of these two approaches to nature of science instruction in an elementary science methods course. To this end, the investigation was guided by the following research questions:

1. What is the impact of explicit versus implicit instruction on preservice elementary teachers’ understandings of the nature of science?
2. What is the impact of contextual versus noncontextual instruction on preservice elementary teachers’ understandings of the nature of science?
3. Does the instructional approach used impact preservice elementary teachers’ ability to apply their understandings of the nature of science to a novel situation?

The Nature of Science

Stanley and Brickhouse (2001) affirmed, “Although almost everyone agrees that we ought to teach students about the nature of science, there is considerable disagreement on what version ought to be taught” (p. 47). In fact, delineation of the nature of science construct has been hotly debated, and some have maintained the impossibility of ever reaching consensus on a specific definition or characterization (e.g., Alters, 1997; Labinger & Collins, 2001; Laudan, 1990; Taylor, 1996). On the other hand, others have emphasized the large degree of agreement in characterizations of the nature of science appropriate for K-16 students (Smith, Lederman, Bell, McComas, & Clough, 1997; McComas et al., 1998; Smith & Scharmann, 1999). These science educators have argued that national and international science education reform efforts have produced standards that delineate a coherent and consistent view of the nature of science. Furthermore, Osborne, Collins, Ratcliffe, Millar, and Duschl’s (2003) Delphi study found substantial overlap between elements of the nature of science generated empirically by an expert panel and nature of science standards outlined in a variety of science education reform documents.

The characterization of the nature of science used in this investigation is consistent with key science education reform documents, as well as with previous investigations in this line of research (American Association for the Advancement of Science, 1993; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; National Research Council, 1996; National Science Teachers Association, 2000). These documents describe scientific knowledge as:

- Empirically based (based upon and/or derived from observations of the natural world).
- Tentative (subject to change with new data and new perspectives on existing data).
- Possessing inherent subjectivity (e.g., theory-laden).
- Partly the product of human inference, imagination, and creativity.

Two additional aspects focus on the roles of observation and inference in the development of scientific knowledge and the definitions of, and relationships between, scientific theories and laws. This characterization of the nature of science provided the conceptual framework for nature of science instruction.
and assessment in the present investigation. For a more detailed description and justification of this characterization, see Lederman et al. (2002).

Global Climate Change

Delineation of three key terms (i.e., the greenhouse effect, global climate change, and global warming) is essential to understanding the socioscientific issue providing the context for nature of science instruction for two of the treatment groups in this study. Moran (2010) provides a useful synopsis of these concepts and issues. Thus, the greenhouse effect refers to the cumulative impact of various atmospheric gases on the temperature of the Earth. There is great confidence among scientists that the greenhouse effect has been heating the Earth for at least 3 billion years, enabling the existence and evolution of living organisms. Global climate change refers to the cycle of temperature shifts and the accompanying changes in other aspects of the Earth system over the long term. Climatologists have generated a vast body of evidence supporting the conclusion that long-term average global temperatures have fluctuated throughout the Earth’s history. Global warming refers to the heating phases in the cycles of global change. The responsibility of humans for global warming and mitigation of global warming is a critical socioscientific issue with potential impact on the entire human race. The international prominence of the arguments about climate change and political and socioeconomic factors (Intergovernmental Panel on Climate Change, 2007; The World Bank Group, 2010), as well as skepticism about causation and data interpretation from some in the scientific community (Christy, 2007; Wigley et al., 2006) make this a potentially fruitful context for nature of science instruction.

The issues of global climate change and global warming (GCC/GW) provide an ideal context for nature of science instruction in the elementary science methods class in that they illustrate many of the target elements of the nature of science. These issues also correspond to the elementary school topics of weather and climate. Observations of global patterns of temperature and inferences about causes for these patterns are the basis for the conclusion of many scientists about human-induced global warming (IPCC, 2007). The scientific mindset that recommends questioning conclusions—even those that carry the weight of consensus—is the same scientific mindset characterized in the nature of science literature as “tentative” meaning that scientists withhold judgment. Examining the information and inferences that led to the concept of global warming and that humans have caused global warming, provides an opportunity to experience the processes that characterize the nature of science. GCC/GW-related investigations are empirically based, and predictions about future global climate are empirically driven. The computer-generated global circulation models from various agencies that produce differing forecasts of temperature change and sea level rise reflect a degree of subjectivity, as they are based upon theoretical constructs and the algorithmic approximations of climatic causes and effects developed by different climatologists. Furthermore, climatologists displayed a great deal of inference, imagination, and creativity in the development of these models. Thus, the socioscientific issue of GCC/GW provides a relevant and potentially effective context for nature of science instruction.

Methods

Experimental Design

This project was designed to assess the relative effectiveness of implicit versus explicit nature of science instruction, with and without being set in the context of instruction about GCC/GW. To this end, a $2 \times 2$ matrix of nature of science and GCC/GW treatments were employed over a period of four semesters (Table 1). The research design utilized a mixed-methods approach in an effort to maximize the

<table>
<thead>
<tr>
<th>Class</th>
<th>Treatmenta</th>
<th>Number of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment 1</td>
<td>Explicit GCC/GW, explicit NOS</td>
<td>15</td>
</tr>
<tr>
<td>Treatment 2</td>
<td>No GCC/GW, explicit NOS</td>
<td>18</td>
</tr>
<tr>
<td>Treatment 3</td>
<td>Explicit GCC/GW, implicit NOS</td>
<td>22</td>
</tr>
<tr>
<td>Treatment 4</td>
<td>No GCC/GW, implicit NOS</td>
<td>20</td>
</tr>
</tbody>
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aTreatments were randomly assigned to intact elementary science methods classes.
complementary strengths of qualitative and quantitative methods. Specifically, the researchers followed a concurrent embedded strategy, in which qualitative and quantitative data were collected simultaneously. As described by Creswell (2009), the concurrent embedded strategy is characterized by a primary method (in this case, qualitative) and a secondary method (in this case, quantitative). In essence, a variety of qualitative data were used to provide rich descriptions of participants’ conceptions prior to, and following each of the four instructional interventions. The quantitative data were used to compare outcomes of the four treatments in a manner that accounted for the variation in individual participants’ initial conceptions.

Participants

The study involved all elementary preservice teachers enrolled in a required three-credit elementary science methods course at a major mid-Atlantic university. In total, the participants numbered 75 (70 females, 5 males), with ages ranging from 21 to 38 years. Most were fourth-year students enrolled in a 5-year Bachelors of Arts/Masters of Teaching (MT) program. The majority (89%) were liberal arts majors, with the other 11% majoring in science or mathematics. Most had completed a total of two undergraduate-level science courses prior to enrolling in the elementary science methods course. The MT program has a rigorous admissions policy focusing on GPA, GRE scores, and prior experience working with children. The consistent application of the MT admission criteria facilitated homogeneity of aptitude and achievement across treatment groups.

The Interventions

Nature of Science Instruction. The nature of science was explicitly addressed in Treatments 1 and 2. Preservice teachers who received explicit nature of science instruction participated in a set of inquiry-based activities taken from a variety of sources (Table S2) and a discussion of one reading assignment (Springston, 1997) selected to teach the target aspects of the nature of science (Table S2). Many of these activities started with the process skills of observing and inferring, followed by explicit nature of science instruction during the activity debrief. For example, the Mystery Tube and the Mystery Box activities required students to observe anomalous behavior of each apparatus and then infer multiple explanations for hidden mechanisms (see Bell, 2008 for a detailed description of this approach). Following this process-skills portion of the lesson, the instructors directed discussion that explicitly connected the activities to relevant aspects of the nature of science, such as tentativeness, subjectivity, and creativity. The Fossil Fragments activity and the Footprints activity required students to make inferences from their observations of actual fossils and drawings of fossil footprints, respectively. Once observations and inferences were shared with the class, the instructors led discussions about how the activities illustrated key aspects of the work of scientists and the nature of science, including the distinction between observation and inference, and parallel distinctions between theory and law. More detailed descriptions of these activities can be found in Matkins and Bell (2007). Several other in-class activities provided opportunities for making explicit connections to nature of science understandings. For example, the Paper Helicopter and Stopper Popper activities focused on experimental design and were used to illustrate creativity and the empirical nature of science. In the Oobleck activity (Sneider, 1985), students used their observations and creative thinking to develop a scientific “Law of Oobleck,” during which they revisited the characteristics of laws and theories.

Global Climate Change/Global Warming Instruction. GCC/GW provided the socioscientific context for instruction in Treatments 1 and 3 (Table S3). This instruction began with a class discussion of students’ prior knowledge of GCC/GW and development of a group list of understandings and beliefs about GCC/GW. Following this prior-knowledge activity, the instructor led discussion in which students compared and contrasted relevant terms, including “greenhouse effect,” “global climate change,” and “global warming.” Additional discussion centered upon the physical processes that support atmospheric warming, the proposed relationship of temperature to atmospheric carbon dioxide, and the role of other greenhouse gases and feedback systems, including clouds, increasing plant growth, and melting ice caps and glaciers. A subsequent data collection activity addressed the importance of cloud feedbacks to the climate system. Participation in NASA’s S’COOL project (Student Cloud Observations Online) involved the participants in the collection and
submission of weather and cloud data that scientists used to correlate with satellite observations. Additionally, the participants read media accounts presenting both sides of the GCC/GW issue from such publications as Science, The Washington Times, Earth, and The World Climate Report. Finally, the explicit GCC/GW treatments included two small-group meetings with scientists whose research related to GCC/GW. In the first meeting, students were instructed to interview the scientist about his/her research and beliefs concerning GCC/GW. The second meeting provided an opportunity to ask the scientist for guidance about what aspects of weather, climate, and GCC/GW were most important for children to learn.

Combining Explicit Nature of Science Instruction With GCC/GW. In the nature of science with GCC/GW treatment group (Treatment 1), the instructor explicitly connected GCC/GW-related activities to relevant aspects of the nature of science. For example, when discussing the limitations of the typical classroom model of the greenhouse effect, the preservice teachers were encouraged to refer to the Mystery Tube activity they had experienced earlier in the semester, with the goal of understanding that scientific models are meant to be useful but cannot be exact copies of reality. Additionally, Treatment 1 participants compared and contrasted the observations and inferences they made as part of the debrief of the Mystery Tube activity to the observations and inferences climate researchers make in developing models of climate change. In a similar manner, all of the nature of science activities (Table S2) were directly connected to the work of scientists in general and climate researchers in particular. During the last few classes of the semester, the class discussed connections between what they had learned about global climate change and the nature of science (e.g., the collection of climate data, the inferential nature of climate change forecasts, and the structure and development of climate models). They also discussed the different opinions about global warming articulated by the various environmental scientists they had spoken with and how these differences illustrated the role of human creativity and subjectivity in the development of scientific ideas.

Implicit Nature of Science Instruction. The implicit nature of science instruction groups (Treatments 3 and 4) participated in the same activities utilized in the explicit nature of science treatments (Table S2), but none received the explicit nature of science debriefing that was a feature of Treatments 1 and 2. This was done in order to limit potential changes in their nature of science understandings to implicit sources (either the GCC/GW instruction and/or the process skills-based methodology promoted by the elementary science methods course). Treatment 3 participants completed all the GCC/GW activities without explicit connections to nature of science such as subjectivity, tentativeness, and the nature of theories and laws.

The Control Group. In Treatment 4, neither GCC/GW nor the targeted aspects of the nature of science were explicitly addressed in class activities and assignments. Many of the non-GCC/GW activities used in Treatments 1–3 were customary components of the class and were again implemented in Treatment 4, with the omission of discussion and debriefing about how these activities illustrated the nature of science. In order to make the instructional time for the intervention roughly equivalent to the other treatments, additional time was devoted to the process skills-based activities, including developing research questions, experimental design, data analysis, and reporting.

TREATMENT FIDELITY. The second author served as the instructor across all four treatments as a way to mitigate the instructor as an extraneous variable. This instructor made every effort in both planning and lesson implementation to preserve the fidelity of the four treatments. In addition, an outside observer who was familiar with the nature of science and GCC/GW instruction observed all treatment-associated lessons to provide feedback to the instructor in an effort to further enhance treatment fidelity.

Data Collection

Data collection spanned the entire semester in which each cohort of participants was enrolled in the elementary science methods course. Data sources included pre- and postquestionnaires, interviews, relevant course assignments, and electronic journal entries. The primary data collection instrument was a nine-item, open-ended questionnaire used to assess understandings of key elements of the nature of science and GCC/GW (Appendix SA). This instrument was based on the Views of Nature of Science (Form B) questionnaire (Matkins & Bell, 2007). Five items focused on the previously mentioned aspects of the nature of science and
four items related to GCC/GW. The instrument was validated through review and subsequent revision by an expert panel. Additionally, a pilot of the instrument was conducted in which three participants completed the instrument and were subsequently interviewed regarding item wording and effectiveness in eliciting the target conceptions. Each treatment group completed the questionnaire as a pretest during the first week of the elementary methods course and as a posttest during the final week of the semester.

Following each administration of the questionnaire, six participants were interviewed (for a total of 48 across treatments and administrations). Participants were purposefully selected for these interviews to produce a stratified sample based on the participants’ range of science backgrounds (from few to many secondary- and college-level science courses). This stratification was based upon the possibility that participants’ views of science and/or GCC/GW could be related to the amount of science course work completed. The semi-structured interviews were intended to validate responses to the pre- or postquestionnaire and to facilitate the generation of in-depth profiles of the participants’ conceptions (Appendix SB). Digressions were common, and the participants’ explanations and reasoning were followed and probed in depth. The interviews lasted about an hour and were audiotaped and transcribed for subsequent analysis.

The researchers collected copies of participants’ relevant journal entries and other related assignments. Collected journal entries included those that addressed nature of science, GCC/GW, and reflections on the participants’ meetings with scientists. Additionally, all lesson plans that the participants created for the elementary science methods course were collected and reviewed. Those that addressed the nature of science and GCC/GW were copied and retained for analysis. All of these artifacts were added to the data corpus as additional data sources for developing and refining participant profiles of nature of science and GCC/GW conceptions and decision making.

Data Analysis

Qualitative. The goal of the qualitative data analysis was to develop generalized pre- and postinstruction profiles for each cohort’s nature of science and GCC/GW understandings derived from systematic examination and re-examination of the available data. Qualitative data included preservice teachers’ VNOS-B questionnaire responses, interview transcripts, assignments, and journal entries. The participants’ data were first analyzed separately using Bogdan and Biklen’s (1992) model of analytical induction and then collectively in order to test the validity of developing assertions. In this approach, working hypotheses to describe/explain the participants’ views were continually formed and then tested against subsequent data. Primary data analysis began with each individual’s VNOS-B and interview responses and then proceeded to include the ancillary data of assignments, reflections, and lesson plans. The variety of data sources permitted triangulation and supported the validity of assertions about each preservice teacher’s pre- and postinstruction understandings. These assertions were combined across participants within each treatment to create profiles of understandings of the targeted concepts. The profiles were re-checked against the data for confirmation or contradiction and modified accordingly. The researchers conducted multiple rounds of profile generation, checking, and modification to adequately reduce and organize the data. Finally these profiles were used in conjunction with representative excerpts to characterize participant pre- and postinstruction conceptions within each of the four instructional interventions.

Since three researchers analyzed the data, it was necessary to establish interrater agreement prior to the analysis of the entire data set. The researchers accomplished this through systematic comparison of separate analyses of three randomly selected data sets. Differences were discussed and assertions mutually revised until consensus was reached. This process resulted in 90% agreement upon the initial round of analysis of the third data set.

Quantitative. The purpose of the quantitative analysis was to compare the profiles developed in the qualitative analysis across treatments to assess participant gains in target conceptions as a measure of the relative effectiveness of the four instructional approaches. Nonparametric statistical tests for dichotomous variables were used for these analyses. First, individual participant profiles developed in the qualitative analysis were scored for each of the target six nature of science and GCC/GW concepts. Participant responses were scored 1’s for each nature of science concept only when their profiles met the criteria delineated in
Lederman et al. (2002) for that particular concept. GCC/GW responses were scored 1’s based upon correspondence with the concepts described in Moran (2010). All other responses were coded 0’s, enabling the researchers to create frequency counts of desired responses for each of the target concepts for each cohort’s pre- and postinstruction profiles. This conservative approach to scoring the responses may be seen as a limitation, since nuances of understandings could not be quantified. However, the limitation is mitigated by the accompanying qualitative descriptions of what the participants actually learned. Appendix SC provides examples of how participants’ responses were scored.

The McNemar Significance of Change test was used to determine whether the changes in the proportions of preservice teachers expressing the desired response differed from pre- to postinstruction for each type of intervention. There were six target nature of science concepts. Thus, for each treatment group, six McNemar tests were done. Accordingly a Bonferroni correction (0.05/6 = 0.008) was used to test each pre–post comparison at alpha = 0.05. Three global warming statements were compared for each treatment group. Accordingly a Bonferroni correction (0.05/3 = 0.017) was used to test each pre–post comparison for an effective alpha of 0.05.

The Kruskal–Wallis test was used to determine differences between the four treatment groups on changes in choice of desired responses for nature of science statements. Since six tests were done at the 0.05 level, a Bonferroni correction was done resulting in a tabular $p$ of 0.008. Comparisons between the treatment groups met this criterion for all six target aspects. These tests were followed up by paired comparisons using a Mann–Whitney test and the same Bonferroni correction.

**Results**

Results of the analysis of the various data indicated significant pre- to posttest differences in the participants’ views of the nature of science and global climate change when the topics were explicitly addressed in the science methods class. Overall, in the treatments where nature of science was taught explicitly, the postinstruction responses reflected desired understandings at a substantially higher rate than the preinstruction responses (Table 2). The following sections present a summary of pre- and postinstruction responses along with representative quotations. The coding system used in these sections delineates whether specified data were collected prior to instruction (pre-) or after (post-) instruction and to identify individual participants (i.e., 1–22). The concluding component of the coding system designates the treatment the participant experienced (i.e., Treatment 1, Treatment 2, etc.) as per Table 1.

**Views of the Nature of Science**

*Preinstruction Views of the Nature of Science.* Nearly all of the preinstruction responses reflected common misconceptions about the nature of science. For example, the majority viewed scientific knowledge

<table>
<thead>
<tr>
<th>NOS Aspect</th>
<th>Treatment 1 Explicit GCC Explicit NOS (n = 15)</th>
<th>Treatment 2 Implicit GCC Explicit NOS (n = 18)</th>
<th>Treatment 3 Explicit GCC Implicit NOS (n = 22)</th>
<th>Treatment 4 Implicit GCC Implicit NOS (n = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empirical nature of scientific knowledge</td>
<td>Pre% 20</td>
<td>Post% 73†</td>
<td>Pre% 17</td>
<td>Post% 90†</td>
</tr>
<tr>
<td>Tentative nature of scientific knowledge</td>
<td>0       80†</td>
<td>6</td>
<td>72†</td>
<td>5</td>
</tr>
<tr>
<td>Role of imagination and creativity</td>
<td>0       53†</td>
<td>11</td>
<td>83†</td>
<td>5</td>
</tr>
<tr>
<td>Subjective nature of scientific knowledge</td>
<td>20       80†</td>
<td>17</td>
<td>67†</td>
<td>32</td>
</tr>
<tr>
<td>Observation vs. inference</td>
<td>27       67†</td>
<td>6</td>
<td>56†</td>
<td>14</td>
</tr>
<tr>
<td>Theories vs. law</td>
<td>0       80†</td>
<td>0</td>
<td>78†</td>
<td>0</td>
</tr>
</tbody>
</table>

† $p < 0.008$ (corrected $p < 0.05$) between pre- and postassessment within treatment.

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as absolute truth. All participants believed that theories become scientific laws when proven true, and most were unable to explicate roles for inference, imagination, or creativity in the development of scientific knowledge (see Table 2). Furthermore, the statistical analysis revealed no significant differences among the preinstruction responses across the four treatments. The following subsections present representative examples of the participants’ preinstruction views.

Preinstructional understandings of the empirical nature of science were consistently naive across all treatments. Most of the participants were familiar with the use of evidence in science, and referred to scientists’ use of observations and data. However, most also indicated that data and observations are the sole source of evidence, and that scientists use data and observations to prove their theories and conjectures. The roles of creative thought and the development of inferences in the development of scientific knowledge were not mentioned by most participants.

Science is to explain our world without the human filter and explain phenomena truthfully in spite of the fact that our senses might sense otherwise. (Pre-16, Treatment 4)

Consistent with the belief that scientists work to prove their ideas, participants viewed theories as weakly supported ideas that were easily and often revised. This misconception about the tentativeness of science as it related to scientific theories was common across pretest responses for all treatments. In addition, participants consistently discussed scientific laws as aspects of scientific knowledge that are proven.

Scientific theory has not stood the test of time or cannot be proven correct 100% of the time, such as the theory of evolution. (Pre-10, Treatment 3)

The majority saw scientific laws as proven beyond a shadow of doubt. For these preservice teachers, scientific laws, along with facts and observations, constituted absolute knowledge that would never change. These participants also expressed the misconception of a hierarchical relationship between scientific theories and laws.

Scientists create theories to explain things they observe about our world. On the other hand, scientists don’t create laws, they discover them. Laws are facts about how our universe works. For example, the Big Bang is a theory about how our universe began; gravity is a scientific law. (Pre-9, Treatment 4)

Laws of science cannot be broken. (Pre-10, Treatment 2)

Newton’s Law #1 is proven and through various testing and experiments it has come to be known as a proven law. Theories, however, have not been proved enough to be changed into laws. (Pre-2, Treatment 4)

Most participants linked the tentativeness of scientific theories to the empirical nature of science. In fact, the collection of new data and the accumulation of counter-evidence were typically cited as the sole source of change. None of the participants mentioned the possibility that scientific theories could change due to new insight or new ways of looking at existing data. Furthermore, the participants viewed scientific knowledge as the accumulation of direct observations and facts, with little role for inferences, even when discussing unobservable entities, such as the particles and structure of the atom.

I believe scientists are quite certain about the structure of the atom. First scientists only had theories of how the atom was constructed until they were able to use very powerful microscopes to see how they were constructed. (Pre-1, Treatment 3)

I feel scientists are strongly sure of the structure of an atom due to chemical structures observed among the elements. The electron microscope presented strong evidence (visually) of the structure. (Pre-5, Treatment 4)

Although most participants expressed the belief that science involved creativity, particularly in “designing experiments” and to “create ideas to be tested,” none discussed the role of creativity of data
interpretation. Several participants cited the “scientific method” as the sole regimen through which scientific knowledge progresses, a view that is at odds with science as a creative endeavor. Prior to instruction, most of these preservice teachers viewed creativity as playing a role only before the real science (i.e., scientific method) is applied.

Science and art are similar because in both genres you have to be creative and willing to experiment. Scientists have to create ideas to be tested while artists create how they want to portray an idea. (Pre-2, Treatment 2)

science is exact, objective, and factual. Art is expressive, subjective, and emotional. (Pre-19, Treatment 4)

The preservice teachers described a degree of subjectivity as inherent to the construction of scientific knowledge. Most participants spoke of subjectivity only in a general way, such as differences in “data interpretation;” “There can be different interpretations of the data based on their knowledge” (Pre-22, Treatment 3). A few of the participants’ preinstructional responses described subjectivity in the negative sense that “…sometimes people ‘see’ simply what they want to believe” (Pre-6, Treatment 1).

Postinstruction Views of the Nature of Science (Treatments 1 and 2). The qualitative analysis indicated substantial postinstruction changes in participants’ nature of science understandings only for the participants in the two explicit nature of science treatment groups (Treatments 1 and 2). In general, these responses reflected a movement from absolute views of science to greater understandings of human factors contributing to the tentative nature of scientific knowledge. Conversely, the postinstruction data reflected very few changes for the participants who received implicit nature of science instruction (Treatments 3 and 4). The overall results are presented in Table 2. Representative postinstruction responses for each of the target nature of science concepts are presented in the following subsections.

Preservice teachers receiving explicit instruction in the nature of science showed marked improvement in their understandings of the empirical nature of scientific knowledge. For example, most developed the realization that factors other than “hard data” influence scientists’ ideas and theories.

Different scientists look at the same topic in different lights drawing from their own theories, backgrounds, and research. While they have the same data, these factors lead them in different directions and approaches to the topic. (Post-12, Treatment 1)

Every scientist comes to his work with a different set of experiences and pre-conceived notions. Just as two people can look at the same drawing/read the same poem and see/hear different things, so too can two scientists deduce different information. (Post-6, Treatment 2)

Whereas references to “proving” scientific ideas as “true” were common in the preinstruction responses, the same ideas were largely absent from the postinstructional responses in the groups who received explicit nature of science instruction.

Science is a process of going through stages to try to find out if you can prove it…Maybe I shouldn’t say “prove,” because things are always changing. You can’t say that this is for certain what happened or what will occur—the’s always room for change. (Post-15, Treatment 1)

The postinstruction responses of the participants who received explicit nature of science instruction indicated important shifts from the participants’ original absolute views of scientific knowledge. While all participants continued to express the belief that theories change because of new evidence, many also described theory change as a result of new ways of looking at existing evidence.

I think theories change…The theories about dinosaur extinction have changed because of new evidence and a new perspective on data. (Post-1, Treatment 1)

Since theories are founded on interpretations of observations, different scientists may propose different theories despite potential use of the same set of data. (Post-11, Treatment 1)

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Additionally, all of the participants who received explicit nature of science instruction discussed the explanatory function of theories, something that was entirely lacking in their preinstructional responses. In fact, in a majority of the postinstructional responses, participants contrasted theories and laws by their function, rather than level of “proof.” Some referred specifically to nature of science activities in which they participated in their class.

A scientific theory explains why something is happening. A scientific law is a summary of observations. It is a generalization. . . . In the tube [activity], we made a law that said that no matter which string we pull, the longer one goes in. This is a summary of all our observations. (Post-18, Treatment 2)

A scientific theory is an explanation of why something happens. A law is a summary of observations— it is a generalization about a phenomenon that is explained by a theory. (Post-2, Treatment 2)

The postinstructional responses of the two explicit nature of science groups also tended to contrast theories and laws by the types of knowledge from which they are derived. The participants described theories as more inferential in nature and scientific laws as generalizations of observational data. This contrasted markedly with their preinstruction misconception that laws are of the same type of knowledge and are, in fact, derived from theories.

In both treatments in which explicit nature of science instruction was employed, the majority of the participants expressed desired postinstructional understandings of the role of imagination and creativity in the generation of scientific knowledge. According to the participants in these two treatments, creativity permeates the scientific process in both the design of experiments and in the interpretation of data. Most agreed that “creativity drives both scientists and artists” (Post-2, Treatment 1). The change in participants’ views was further emphasized by their rejection of the conception of a single scientific method. Contrary to their prior beliefs, they allowed for many methods and creative approaches to the process of generating scientific knowledge.

Not everything can follow the scientific method—like, if you’re trying to find out about dinosaurs . . . I don’t think that every time someone is going to state a hypothesis before they discover something. (Post-1, Treatment 1)

The view that science is completely rational and objective was rejected by a large majority of the participants who experienced explicit nature of science instruction. Rather, they described how scientists’ backgrounds, personal views, and biases toward the data potentially played a role in their interpretation of the data. Contrary to their preinstructional responses, none of the participants cast subjectivity in a totally negative light; they began to see disagreements as a natural outcome of the role of inference in the development of scientific ideas.

It is possible that different people make different inferences from the same data and observations. (Post-17, Treatment 2)

Different conclusions are the result of different interpretations of data. Scientists draw varying inferences based on unique personal experiences, backgrounds, and systems of thought and belief. Every individual is the product of a unique set of life experiences, program of study, and mindset. All of these factors affect how a researcher interprets a given set of data. (Post-11, Treatment 1)

Postinstruction Views of the Nature of Science (Treatments 3 and 4: Implicit Instruction). Postinstructional responses for participants in the two implicit nature of science groups remained largely unchanged from their preinstructional responses. These participants continued to view scientific knowledge as absolute and the generation of scientific knowledge as an objective process with little role for inference, creativity, and multiple perspectives.

Scientists are fairly certain that the atom, the building block of matter, is organized rigidly & symmetrically with protons, neutrons, & electrons. Studies have been based on sound experiments utilizing the scientific method & electron microscopes. (Post-19, Treatment 4)
When experimentation has been done on all possible options and a theory still stays true, then it can become a law. (Post-14, Treatment 3)

Theories aren’t proven, laws are proven. The law of thermodynamics always works, the theory of evolution hasn’t been proven. Theories are susceptible to change, laws aren’t. Laws always work and have been proven to work. (Post-18, Treatment 4)

Art is more flexible and feeling-based while science is fact-based and only has one explanation if it can be explained. (Post-16, Treatment 3)

People interpret things differently… They conform the data to fit what they want it to. (Post-15, Treatment 4)

**Statistical Analysis.** A summary of the proportion of preservice teachers giving desired responses for each of the six target aspects of the nature of science is provided in Table 2. Inspection of Table 2 indicates the following: Only small proportions of the preservice teachers gave the desired response at the pretest. There was little change in the desired direction for preservice teachers who received only implicit instruction in the nature of science (Treatments 3 and 4). The largest changes were for preservice teachers who received explicit instruction in the nature of science (Treatments 1 and 2).

Statistical analyses using McNemar’s significance of change test confirmed these observations. There were no statistically significant pre- to postinstruction changes on any item for implicit nature of science groups (Treatments 3 and 4). For both groups that received explicit nature of science instruction (Treatments 1 and 2) changes for each of the six items were statistically significant at \( p < 0.008 \) (corrected \( p < 0.05 \)). Table 3 presents the data for the explicit nature of science treatments as pre- to postinstruction gains in desired responses. The nonparametric analyses revealed no statistically significant differences across these gains.

**Global Climate Change/Global Warming**

**Preinstruction Views of GCC/GW and the Nature of Science.** The majority of the preservice teachers in all treatment groups held preinstruction misconceptions about GCC/GW (Table 4). These included beliefs that the greenhouse effect is both unnatural and (always) harmful, that scientists hold consistent beliefs about the impacts of GCC/GW, and that the greenhouse effect is either a scientific theory, because it is unproven, or conversely, a scientific law because it is proven.

Preinstruction responses to questionnaires and interviews in all treatments ranged from statements about GCC/GW that contained multiple misconceptions to responses that used some correct descriptions and terminology (see Table 4). The ideas found in the following examples are representative of the preinstruction views of the participants in all treatments. Many believed that the ozone hole was the primary causal factor in the greenhouse effect, that the greenhouse effect and global warming were synonymous.

It [the greenhouse effect] is caused by a hole in the ozone layer which allows stronger sun rays in. The heat of the sun is slowly heating the temperature of the earth causing the polar caps to begin melting. This increases the amount of water in the ocean and leads to erosion on the shores and loss of land. (Pre-2, Treatment 1)

### Table 3

**Comparison of pre–post gains for explicit NOS treatments**

<table>
<thead>
<tr>
<th>NOS Aspect</th>
<th>Treatment 1 Explicit GCC Explicit NOS ((n = 15)) Pre–Post Gains (%)</th>
<th>Treatment 2 Implicit GCC Explicit NOS ((n = 18)) Pre–Post Gains (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empirical nature of scientific knowledge</td>
<td>53</td>
<td>73</td>
</tr>
<tr>
<td>Tentative nature of scientific knowledge</td>
<td>80</td>
<td>66</td>
</tr>
<tr>
<td>Role of creativity</td>
<td>53</td>
<td>72</td>
</tr>
<tr>
<td>Subjective nature of scientific knowledge</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>Observation vs. inference</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Theories vs. law</td>
<td>80</td>
<td>78</td>
</tr>
</tbody>
</table>

*Note. No gains were significant at \( p < 0.008 \) (corrected \( p < 0.05 \)) across treatments.*
The greenhouse effect is the gradual loss of the protective ozone layer due primarily to the release of certain man-made gases. The loss of the filter is allowing more of the sun’s rays to pass through the atmosphere causing a general warming of the Earth’s surface. (Pre-2, Treatment 3)

In a few instances, students expressed correct understandings of the greenhouse effect and its mechanisms. Even these students expressed other misconceptions, such as characterizing the effect as a trapping of energy in the atmosphere, listing isotopes as greenhouse gases (C14), naming gases as greenhouse gases that did not occur naturally prior to the 20th century (chlorofluorocarbons—CFCs, first synthesized in 1928), and failing to distinguish between particles and gases. Even the most correct descriptions did not reflect a level of understanding necessary for the respondents to accurately teach the concepts to children. The following excerpts from student responses were the most correct preinstruction responses from two class sets.

Certain particles, CFCs, C14, and others form a blanket in the stratosphere that “insulates” the earth—keeps the earth warm by keeping heat emitted from the sun around the earth. (Pre-1, Treatment 1)

Radiation from the sun enters into the earth’s atmosphere and it is both absorbed by the earth and reflected by it. Part of the light and heat energy that is reflected gets trapped by the atmosphere and warms the earth. (Pre-15, Treatment 2)

Across all treatments, participants’ preinstruction explanations about whether the greenhouse effect is a theory or a law reflected conventional understandings about theories as unproven conjecture and laws as proven in an absolute sense.

[The greenhouse effect] is a theory. Since there is a difference of opinion on why the earth is warming, the greenhouse effect is only a theory. If someone could prove that the greenhouse effect explains the earth’s warming 100% of the time, then it could be a law. (Pre-12, Treatment 4)

Over 60% of the participants indicated willingness to support the development of alternative energy sources even if the actions taken raised their taxes or cost them in other ways. Most of the preservice teachers supported taxation for the proposed government program with reasoning that lacked critical consideration of the nature of science or the issue of global warming. For these participants, a general notion of “saving the world” was enough reason to support conservation and environmentally friendly technology.

Yes—anything to help save our Earth would be worth it. Eventually, they would hopefully be able to get the prices down. (Pre-18, Treatment 2)
Postinstruction Views of GCC/GW and the Nature of Science. As expected, only in the explicit GCC/GW groups did participants demonstrate substantial postinstruction gains in GCC/GW understandings. Although not every participant in the explicit GCC/GW groups moved toward correct and complete understandings of the phenomena, a large portion of each class did (Table 4). The following sections highlight the changes in participant understandings of global climate change and the nature of science as it intersected with the study of global climate change.

At the completion of the explicit GCC/GW instruction many more participants held correct understandings of the greenhouse effect. The understandings expressed in their posttest questionnaires were generally more thorough and showed a deeper understanding of the processes involved in the greenhouse effect. Some respondents made direct connections between the nature of models in general and the greenhouse effect in particular.

The greenhouse effect is a proposed explanation for increased Earth temperatures. It is not the same as “global warming,” and often receives a negative connotation. The greenhouse effect is a model, much like a real greenhouse . . . that in turn insulates the earth’s surface—we probably couldn’t live on earth without some degree of greenhouse effect. (Post-9, Treatment 1)

It is the net warming of the earth because some of the sun’s energy is absorbed by the earth and then re-emitted and absorbed in the atmosphere. But some of the sun’s energy escapes back into space. It does not cause “global warming;” it is actually the phenomenon that allows the earth to be at this temperature. Otherwise temperatures would drop below 0°. (Post-20, Treatment 3)

Prior to instruction, most participants in all treatments based their choice of “theory” or “law” to characterize the greenhouse effect upon whether they understood the greenhouse effect to be proven in an absolute sense. Explicit instruction about GCC/GW alone did not lead to gains in participants’ understandings of the differences between scientific theories and laws. In contrast, after explicit nature of science instruction (Treatments 1 and 2), about 70% of the participants responded to item 8 of the questionnaire with explanations about the nature of scientific theories and laws. Furthermore, they used the science process nomenclature of observation and inference, as they had been taught in the course, to clarify their reasoning.

The greenhouse effect is a law—if it is described as the reflective effect of the atmospheric gases on radiant energy. If, however, it is described as being the effect of changes in atmospheric composition on global climate change, it is a theory. Laws are based on direct observations while theories are founded on inferences, which involve the interpretation of observations. (Post-11, Treatment 1)

If it’s based on observations—such as records of relative amounts of gas in a sample of the atmosphere—it’s a law. If it’s based on inferences—such as an explanation about why the Earth’s temperature is rising—it’s a theory. I think it’s probably a theory because it’s a possible explanation of why temperatures are rising. (Post-13, Treatment 2)

Although there were few differences between the postinstructional responses of the Treatments 1 and 2 participants, substantial differences were reflected between their responses to item 9 of the questionnaire, which was designed to elicit information on decision making on a GCC/GW issue. The majority of participants were in favor of supporting hypothetical government-sponsored alternative energy programs, in both their pre- and postinstructional responses. However, only the participants who received explicit instruction in both the nature of science and GCC/GW were able to articulate justifications for their support of government-sponsored alternative energy programs that reflected target conceptions of the nature of science. In general, these participants made reference to using their new understandings of the roles of subjectivity, evidence, and consensus in science when making decisions on socioscientific issues.

Studying [the nature of science and GCC/GW] made me more aware of subjectivity and how many variables are surrounding the way the world around us behaves. (Post-5, Treatment 1)

Yes, this is an important issue that must be addressed. Having alternatives can only benefit us if they are shown to be efficient alternatives to natural resources such as oil, coal, etc. (Post-12, Treatment 1)
If consensus within a majority of the scientific community were reached about the earth warming at a potentially detrimental rate, yes I would support the move to more costly alternative energy sources.

(Post-1, Treatment 1)

**Statistical Analysis.** A summary of the proportion of preservice teachers giving desired responses for each of the three statements about global warming is provided in Table 4. For the "greenhouse effect" pre- to postinstruction changes were statistically significant for the two treatments with explicit global warming instruction (Treatments 1 and 3) but not for the other two treatments. The second response category focused more on the nature of science conceptions of scientific theories and laws than on GCC/GW understanding. Nonetheless, Treatment 1 and 2 participants made statistically significant improvements in their abilities to apply desired conceptions of theory and law to the socioscientific context of global warming, whether they had been taught GCC/GW explicitly. Only the responses of Treatment 1 participants (Explicit GCC/GW and Explicit NOS) reflected significant gains in the ability to justify support for government energy policy using target aspects of the nature of science. Incorporation of the nature of science in decision making was much more likely when both the nature of science and the socioscientific concept of GCC/GW instruction were explicit.

**Discussion**

The purpose of this investigation was to assess the relative impacts of explicit versus implicit nature of science instruction as well as the relative efficacy of teaching nature of science as an isolated topic versus teaching it as an integral part of a socioscientific issue. The results of the investigation support the necessity of explicit nature of science instruction. Only the preservice elementary teachers in groups receiving explicit nature of science instruction made substantial gains in their understandings of this elusive construct. None of the participants learned target aspects of the nature of science implicitly through instruction about GCC/GW, despite the fact that this socioscientific issue and the instruction related to it were entirely consistent with the target nature of science characteristics. In this regard, our results are aligned with those of recent investigations supporting the necessity of explicit nature of science instruction (Bell, Blair, Crawford, & Lederman, 2003; Bell, Lederman, & Abd-El-Khalick, 2000; Khishfe & Abd-El-Khalick, 2002; Morrison et al., 2009; Shapiro, 1996). It is important to note that instructional activities consistent with currently accepted ideas of nature of science (e.g., footprints activity, science process skills activities, discussions of socioscientific issues) were employed in all treatments of this investigation, but were not in themselves enough to change participants’ views in the absence of explicit nature of science instruction. Thus, the results of this investigation add to the body of literature indicating that nature of science instruction is most effective when it is explicit in lesson objectives, purposively taught, and specifically evaluated.

The results in regard to context of nature of science instruction are unambiguous. Participants made substantial gains in their understandings regardless of whether nature of science instruction was situated within the socioscientific issue of GCC/GW. Teaching nature of science without connecting it to a socioscientific issue was just as effective as teaching it as an integrated component of GCC/GW instruction. Moreover, participants receiving explicit nature of science instruction without GCC/GW instruction were able to apply the general knowledge they had gained about scientific theories and laws to specific examples within the socioscientific issue of GCC/GW. To our knowledge, this is the first time such transfer of understandings about the nature of science has been reported for preservice teachers. Furthermore, the results contrasts with those of a previous investigation (Abd-El-Khalick, 2001), where preservice elementary teachers were for the most part unable to appropriately apply their postinstructional understandings of the nature of science to unfamiliar science content.

On the other hand, teaching the nature of science within the context of GCC/GW produced apparent gains in the ability of the preservice elementary teachers to use their knowledge of the nature of science in decision making. Prior to instruction, participants’ pretest responses indicated that they based their decisions on whether to support government-sponsored alternative energy programs on nonscientific factors. Consistent with previous investigations (Bell & Lederman, 2003; Fleming, 1986a,b; Sadler, Chambers, & Zeidler, 2004), participants’ preinstruction decision making tended to be influenced most by personal values and experiences. In particular, Sadler et al. (2004) found that high school students studying global warming
tended to compartmentalize scientific knowledge, persisting in using personal, social, and moral considerations despite an emphasis in their science class on scientific evidence. The postinstruction responses of the Treatment 1 participants (explicit NOS and GCC) are consistent with a move away from compartmentalization into more scientific reasoning in their responses to the decision making prompt in the survey.

After instruction, only Treatment 1 participants (explicit GCC/GW and explicit NOS) demonstrated significant gains in their ability to justify support for government energy policy using target aspects of the nature of science. Thus, participant references to the nature of science were more likely when both the nature of science and the socioscientific concept of GCC/GW instruction were explicit. These results provide preliminary evidence that teaching the nature of science in the context of a socioscientific issue may be a successful strategy for facilitating students’ ability to apply their understandings of the nature of science in decision making. Science educators have argued that learning to use one’s conceptions of the nature of science in decision making is an important educational outcome in itself and, as such, warrants explicit instruction (Bell & Lederman, 2003; Sadler et al., 2004). Further research is needed to explore the role that context plays in facilitating students’ abilities to use their knowledge of the nature of science in decision making.

Sadler (2004) recommended that research be conducted on the development of meaningful personal connections in socioscientific contexts to encourage students to integrate knowledge. The development of personal connections involves meaningful engagement with the socioscientific issue, including the development and use of strategies that “help students envision the connection that exists between more global issues and themselves” (Sadler, 2004). Results from the current study indicate that students were engaged at a level that enabled a high degree of integration of the nature of science and the scientific issue of GCC/GW. Furthermore, science process skills—a topic that these elementary teachers recognized as something they were expected to teach—were explicitly connected to the nature of science and GCC/GW which, in turn, was explicitly connected to common elementary science topics such as clouds and weather. It appears that the participants found this high level of integration particularly meaningful as they learned about science and how to teach it.

The overall picture emerging from these results is that, while setting instruction in the context of authentic science content and issues may be desirable, it may not be necessary when the primary goal is for students to understand key aspects of the nature of science. This conclusion contrasts with the literature arguing for the necessity of contextualized nature of science instruction (e.g., Clough, 2003; Johnston & Southerland, 2002; Olson & Clough, 2001; Ryder et al., 1999; Smith & Scharmann, 1999). Then again, our results are consistent with those of Khishfe and Lederman (2006), who reported positive outcomes for ninth-grade environmental science students, regardless of whether nature of science instruction was integrated within a socioscientific issue. Our investigation adds to the findings of Khishfe and Lederman (2006) by focusing on elementary preservice teachers, providing a direct comparison of implicit versus explicit nature of science instruction, and by addressing socioscientific issue decision making.

It is important to note that the results of this investigation do not necessarily suggest that the nature of science should be taught as a stand-alone subject. Rather, they can be seen as emphasizing that there is more than one way to “contextualize” nature of science instruction. The second author, who was the elementary science methods instructor in the present investigation, has a history of teaching process skills throughout the elementary science methods course. In fact, one of her instructional goals is to help elementary teachers gain the confidence and skills to teach the processes of science. As we considered where to provide nature of science instruction in Treatment 3 of the investigation (Explicit NOS, no GCC/GW), the most logical fit appeared to be along with the teaching of process skills. Furthermore, our approach to nature of science instruction typically began with an activity designed to teach specific process skills (such as observation, inference, measurement, and experimental design), then to extend the lesson to address relevant aspects of the nature of science. Thus, the nature of science was presented as a natural consequence of the particular scientific process being addressed, rather than as a disconnected add-on to the lesson.

Additional research focusing on this process skills-based approach to nature of science instruction used in this investigation has also demonstrated positive outcomes. Bell, Toti, McNall, and Tai (2004) reported that preservice secondary teachers who experienced process skills-based nature of science instruction developed
targeted understandings of the nature of science and did not conflate process skills and nature of science (an issue reported in previous investigations, e.g., Abd-El-Khalick et al., 1998; Bell et al., 2000). In addition, analysis of lesson plans and classroom observations indicated that the preservice secondary teachers went on to develop and teach their own nature of science lessons during both their student teaching and induction year experiences. The results of the present investigation in combination with those of Bell et al. (2004) are thus consistent with situated learning perspectives. Preservice teachers, who experienced nature of science instruction within the context of the more familiar science process skills, both learned and applied what they learned in their own science instruction. These findings warrant additional research into the efficacy of teaching nature of science in the context of science process skills.

Although further research is needed before generalizing these results to other situations, this investigation provides support for including explicit instruction on the nature of science in the elementary science methods course. Further, the preservice elementary teachers in this study achieved all of the target nature of science conceptions regardless of whether the instruction was situated in the context of a socioscientific issue. Future investigations are needed to further explore the efficacy of situating nature of science instruction within the context of other socioscientific issues (e.g., genetic manipulation, cloning, and nuclear energy) in order to explore the generalizability of the findings reported here. It is also important that such assessments be applied to other groups of preservice teachers, whose preparation and background knowledge may influence the outcomes differently. For example, secondary preservice teachers’ more substantial scientific backgrounds may produce different results when nature of science instruction is integrated with socioscientific issues in secondary science methods courses. Also, it is important to extend this line of research longitudinally to address the critical question of whether preservice teachers are able to translate their nature of science understandings into classroom instruction. In one of the rare examples of longitudinal studies, Akerson, Morrison, and McDuffie (2006) found that few of the preservice elementary teachers in their study retained improved nature of science understandings even one semester after their science methods course. The teachers who did retain improved understandings were those who remembered specific classroom activities and were able to connect these activities to nature of science concepts. This finding suggests the need for future research that explores the contextualized approach for promoting long-term retention of nature of science conceptions.

During the exit interviews, we asked whether this project would influence the participants’ future instruction. Many of the Treatment 1 (explicit GCC/GW, explicit NOS) participants’ comments indicated intent to incorporate their new understandings of the nature of science into their teaching, as illustrated in the following comment:

[Studying GCC/GW and the nature of science] makes you realize that science isn’t always exact and so you have a responsibility to teach both sides and all angles of a scientific issue. (Post-1, Treatment 1)

We believe that explicit nature of science instruction has great potential for developing elementary teachers with more complete understandings of the nature of science, and are intrigued by the possibility that situating it within the context of socioscientific issues may positively impact their decision making. While it is unlikely that elementary teachers will learn everything we would like for them to know about the scientific enterprise in the elementary science methods course, the results of this investigation demonstrate that it is a good place to start.

References


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