PRESERVICE SCIENCE TEACHERS' NATURE OF SCIENCE INSTRUCTION AND ITS IMPACT ON PUPIL LEARNING

Abstract: This study characterized preservice teachers' nature of science instruction during student teaching and how this instruction impacted their pupils' understandings. As part of their teacher preparation program the 15 participants experienced instruction specifically designed to address constraints to teaching nature of science reported in previous studies. Participants' understandings of nature of science and intentions to teach about nature of science were assessed by the VNOS-C and follow-up interviews. Nature of science-related instructional practice was assessed through lesson plan analysis, classroom observations, and exit interviews. Pupil understandings of the nature of science were assessed through pre- and post-test administrations of a shortened version of the VNOS-C and through exit interviews. Results indicated that the preservice teachers achieved desired understandings of nature of science and that they developed strong intent to teach about nature of science during their student teaching experiences. Furthermore, analysis of classroom observation notes and lesson plans indicated that all of the participants included explicit instruction on targeted aspects of nature of science. Pupil understandings of targeted aspects of the nature of science improved over the course of the study. The results are promising in that they indicate that beginning teachers can be taught to address the nature of science appropriately during student teaching, and that their instruction can have a positive impact on their pupils' understandings.

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Introduction

Developing a scientifically literate society has come to be accepted as a principal goal of science education (American Association for the Advancement of Science [AAAS], 1993; McComas, 1998; National Research Council [NRC], 1996). Achieving scientific literacy involves providing people with an understanding of science and the scientific enterprise that enables them to make reasoned decisions and engage in debate about scientific issues (Driver, Leach, Millar, & Scott, 1996; Lederman, 1999; Ryder, 2001). It is widely recognized that science instruction designed to achieve scientific literacy must go beyond traditional approaches that emphasize content, to a more balanced approach that includes explicit instruction about how scientific knowledge is developed, the characteristics of that knowledge, and the nature of the scientific enterprise. Thus, the nature of science has received increased attention in recent years as a primary component of scientific literacy (AAAS, 1993; Bell & Lederman, 2003; NRC, 1996).

Unfortunately, the research into teachers' and students' understandings about the nature of science consistently indicates that neither K-12 teachers nor their students hold views that are in line with the current conceptions (e.g., Abd-El-Khalick & Lederman, 2000; Abell & Smith, 1994; Akerson, Abd-El-Khalick, & Lederman, 2000; Duschl, 1990; Gallagher, 1991; King, 1991; Lederman, 1992; Ryan & Aikenhead, 1992). Historically, nature of science research has followed two principal avenues related to science teachers: a) assessing and improving teachers' understanding of the nature of science; and b) examining the connection between teacher beliefs and classroom practice (Lederman, 1992). These lines of research are connected by the reality that teachers are unlikely to teach effectively what they themselves do not understand.

Several studies have demonstrated the ineffectiveness of implicit nature of science instruction and have pointed to the necessity of instruction that is purposive, explicit, and reflective in regard to nature of science tenets (Abd-El-Khalick, Bell, & Lederman, 1998; Bell, Lederman, & Abd-El-Khalick, 2000; Bell, Blair, Crawford, & Lederman, 2003). More recently, researchers have used the term "explicit reflective" when referring to this type of nature of science instruction (Abd-El-Khalick, 2001; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000; Akerson et al,, 2000; Akerson, Morrison, & McDuffie, 2006; Akerson & Volrich, 2006; Kfishe & Abd-El-Khalick, 2002; Scharmann, Smith, James & Jensen, 2005). Regardless of what the approach is called, effective nature of science instruction requires that nature of science concepts be taught purposefully, rather than implicitly, and that students be given opportunities to develop and discuss with one another their emerging ideas about the scientific enterprise.

Indeed, explicit nature of science instruction has been shown to effect positive changes in preservice teachers' understandings of the nature of science (e.g., Abd-El-Khalick et al., 1998; Akerson et al., 2006; Bell et al., 2000; Gess-Newsome, 2002). However, even if teachers come to achieve desired understandings of the nature of science, this does not necessarily mean that they will be able to teach it effectively. In fact, substantial attention has been directed at this issue in recent years, and thus explores the assumption that teachers' beliefs about the nature of science and their instructional practice are closely linked. These investigations demonstrate that teachers' beliefs about the nature of science are not always reflected in their instructional practice (Abd-El-Khalick et al., 1998; Akerson & Abd-El-Khalick, 2003; Brickhouse, 1989, 1990; Duschl & Wright, 1989; Gallagher, 1991; Lederman, 1995; Lederman, 1999; Lederman & Zeidler, 1987; Mellado, 1997; Southerland, Gess-Newsome, & Johnston, 2003; Tsai, 2007; among others). These studies have accumulated substantial evidence indicating that this relationship is mediated by a number of factors, including lack of resources and experience for teaching the nature of science, concerns about students and classroom management, lack of support from mentor teachers, and the view that the nature of science is less important than other instructional objectives, among others (Abd-El-Khalick et al., 1998; Bell et al., 2000; Gess-Newsome & Lederman, 1995; Southerland, Gess-Newsome, & Johnston, 2003).

However, a subtle mitigating factor that may impede instruction about the nature of science is teachers' tendency to conflate teaching science process skills with teaching the nature of science. For example, preservice teachers in the Abd-El-Khalick et al. (1998) investigation typically cited examples of hands-on activities that addressed process skills such as observation and inference when asked how they had taught about the nature of science. Follow-up questioning, as well as classroom observations and lesson plan analysis made it clear that they had failed to include explicit connections to the nature of science in their instruction. The researchers concluded that a potential source of this conflation was the science methods instructor's approach of combining instruction about the nature of science with instruction about how to teach the nature of science.

As a possible remedy, the researchers proposed a new instructional sequence, in which instruction about the nature of science was clearly separated from instruction about methods of teaching nature of science. An assessment of this revised instructional approach revealed that it met with some success in that a somewhat higher percentage of preservice teachers attempted explicit nature of science instruction during their student teaching experiences (Bell et al., 2000).

Bell, Toti, McNall, & Tai (2005) speculated on a different source reason that preservice teachers might emphasize process skills instruction over nature of science instruction. As preservice teachers are challenged to develop instruction that goes beyond the traditional emphasis on content, it may be that they default to instruction about science process skills because they are more familiar and concrete. As science majors, most secondary preservice teachers experience didactic instruction that heavily emphasizes science content. To a lesser degree, they typically complete laboratory and field course work emphasizing a wide range of process skills, such as observing, measuring, predicting, and classifying. Compared to familiar content and process skills instruction, nature of science concepts and the activities used to teach them are more novel, abstract, and complex (Southerland, Gess-Newsome, & Johnston, 2003). In many recent studies, science educators have made use of the process skills of observation and inference in hands-on activities and demonstrations that are presented as analogies to the nature of science (e.g., Abd-El-Khalick et al., 1998; Akerson et al,, 2000; Bell et al., 2000). Is it any wonder, that preservice teachers who experience such instruction tend to gravitate toward science process skills (with are both more concrete and familiar) when they attempt to enact nature of science instruction (Bell et al., 2005)?

Bell et al. (2005) proposed that it might be effective to capitalize on beginning teachers' familiarity with process skills instruction when encouraging them to teach about the nature of science. To test this proposition, the researchers purposely introduced preservice teachers to explicit nature of science within the context of teaching familiar science process skills. The researchers modeled more than a dozen activities designed to teach nature of science through process skills-based instruction. After each activity, participants were encouraged to reflect on the process skill and nature of science portions of the lessons. As part of the instructional treatment, the researchers emphasized how nature of science instruction can complement process skills activities, and in many cases is a natural extension of activities designed to teach about science process skills. The researchers also supported process skills-based nature of science instruction through discussion of the two complementary sets of inquiry standards in the *National Science Education Standards (NSES)*. The *NSES'* call for students to develop skills in both doing inquiry and knowing about inquiry is analogous to teaching inquiry (process) skills and the nature of science (Table 1).

Table 1
Examples of NSES standards for abilities to do and understandings about scientific inquiry and how these concepts relate to process skills and nature of science.

Abilities to do Scientific Inquiry (Process Skills)	Understandings About Scientific Inquiry (Nature of Science)
▪ Identify questions. ▪ Design & conduct investigations. ▪ Use technology & mathematics. ▪ Formulate explanations using logic & evidence. ▪ Communicate & defend a scientific argument.	▪ Scientists use many methods to conduct a wide variety of investigations. ▪ Scientists rely on technology & mathematics. ▪ Scientific explanations must: - be logically consistent - abide by rules of evidence - be open to questions & modification - be consistent with current scientific knowledge.

During the 15 participants' student teaching experiences, the researchers characterized the quantity and quality of explicit nature of science instruction. Immediately following student teaching, the researchers characterized the participants' understandings of the nature of science using the VNOS-C instrument (Lederman, Abd-El-Khalick, Bell, and Schwartz, 2002) and follow up interviews. The results indicated that the participants achieved desired understandings of the nature of science, and they included substantial amounts of explicit instruction about specific aspects of the nature of science in their instruction. Furthermore, they continued to teach about the nature of science and develop new activities for teaching the nature of science after they had completed their teacher preparation and into their induction year as science teachers (Bell et al., 2005).

Bell et al. (2005) did not attempt to assess what pupils learned about the nature of science from the preservice teachers' instruction. So, while the investigation demonstrated the impact of process skills-based instruction on preservice teachers' understandings and instructional practice about nature of science, it did not address the definitive question for any intervention in teacher education: What impact does the intervention ultimately have on K-12 pupils? Or in other words, what is the value added in terms of pupil learning?

The purpose of the present investigation is to address these questions by assessing changes in pupils' understandings as a result of instruction employed by preservice teachers who experienced the process skills-based approach to nature of science instruction in our teacher education program. In so doing, we hope to begin to provide the assessment of teacher education in regard to the nature of science—what is the ultimate impact on pupil learning? To this end, our research questions included:

1. What is the impact of the process skills-based instruction on secondary preservice teachers' understandings of the nature of science?

2. What is the impact of the process skills-based instruction on secondary preservice teachers' instructional practice during student teaching?
3. What is the impact of secondary preservice teachers' instructional practice about the nature of science on pupil learning?

The Nature of Science

The nature of science may be defined as the values and assumptions inherent to scientific knowledge and its development (Lederman, 1992; Lederman & Zeidler, 1987). While there is little debate regarding whether the nature of science should be taught, the exact characterization of the nature of science has been debated in recent years (Alters, 1997; Labinger & Collins, 2001; Laudan, 1990). However, in regard to those aspects of the nature of science appropriate for K-16 students, the national reform documents and science education literature have emphasized considerable agreement (AAAS, 1993; McComas, Clough, & Almazroa, 1998; NRC, 1996; NSTA, 2000). Furthermore, in a recent Delphi study, Osborne, Collins, Ratcliffe, Millar, and Duschl (2003) found substantial overlap between the characterization of the nature of science in national reform documents and by an expert panel of 23 scientists, science educators, and historians, sociologists and philosophers of sciences.

The characterization of the nature of science used as a foundation in this investigation is consistent with current science education reform documents and previous investigations in this line of research (Abd-El-Khalick et al., 1998; Bell et al., 2000; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001). In this view, science is depicted as a particular way of knowing, exhibiting the following characteristics:

a) Tentativeness (Science is self-correcting in that all forms of scientific knowledge are subject to change with new evidence and new ways of interpreting existing evidence.)
b) An empirical base (Scientific knowledge is based upon, and must be consistent with evidence.)
c) A connection to both observation and inference (as opposed to observation alone).
d) Subjectivity (Scientists interpret empirical evidence in light of current scientific perspectives and their own values, knowledge and experiences.)
e) Creativity (Science is inherently a creative process. There is no fixed set of steps that scientists follow in the development of scientific knowledge, and therefore, no universal scientific method.)
f) Scientific theories and laws are conceptually distinct and serve different purposes.

The authors recognize that, despite considerable consensus for these aspects of the nature of science, there exists no single characterization that fully describes all of science and scientific knowledge. Moreover, the nature of science itself is tentative and therefore, presents a moving target (Lederman, 1992). However, the present characterization is a reasonable place to start, given the support for it and given our goal of combating students' misconceptions of science, which tend to reflect a view that is too absolute and positivistic (McComas, 1996).

Methods

This study was descriptive in nature, designed to ground emerging theories in data (Strauss & Corbin, 1998). Our efforts were aimed at providing insight into how a process skills-based nature of science instruction may be translated from science educator to pre-service teachers, and then to pupils in a secondary school setting.

Participants

Fifteen preservice science teachers (14 females and 1 male) participated in the study (Table 2). Ages ranged from 21 to 42 years. The participants were enrolled in a mid-sized public university in the mid-Atlantic region of the United States. At the beginning of the study all 15 individuals were seeking certification at the secondary-level in four different science disciplines: 5 in biology, 1 in chemistry, 7 in earth science, and 2 in physics.

Table 2
Background information for the 15 participants.

Name	**Major**	**Area of Licensure**	**Program**
Christina	Environmental Science	Earth Science	PG/MT
Eddie	Physics	Physics	BA/MT
Erica	Environmental Science	Earth Science	BA/MT
Hannah	Physics	Physics	BA/MT
Jane	Environmental Science	Earth Science	BA/MT
Joanne	Environmental Science	Earth Science	PG/MT
Kelly	Biology/German	Biology/German	BA/MT
Kendra	Environmental Science	Earth Science	BA/MT
Lisa	Chemistry	Chemistry	PG/MT
Maria	Biology	Biology	BA/MT
Melissa	Biology	Biology	BA/MT
Monica	Environmental Science	Earth Science	BA/MT
Morgan	Biology	Biology	BA/MT
Paula	Environmental Science	Earth Science	PG/MT
Rose	Biology	Biology	BA/MT

Note: BA/MT = bachelor of arts or bachelor of science/master of teaching;
PG/MT = postgraduate/master of teaching

The competitive nature of admissions to the teacher education program serving as the context for this research project created a participant pool possessing relatively strong educational backgrounds. By the completion of the investigation all participants had completed a Bachelor of Arts or Bachelor of Science in their respective science disciplines, a Master of Teaching and had obtained licensure to teach secondary science in the host state of the university.

Context and Intervention

The context of the study, data collection procedures, and data analysis paralleled a previous investigation in this line of research (Bell et al., 2005). Both this investigation and the previous one sought to characterize the nature of science understandings and instructional practices of preservice teachers who had been taught with the process skills-based approach to nature of science instruction. The primary difference between the two was that in addition to these goals, the previous investigation sought to track the participants' instructional practice after they had completed the teacher education program, while the present investigation sought to assess the impact of the preservice teachers' instruction on their pupils' understandings of the nature of science. Together, the two investigations were designed to assess the impact of the process skills-based approach to nature of science instruction on the understandings and instructional practices of preservice teachers, induction year teachers, and ultimately, the understandings of their pupils.

The participants were enrolled in a combined master of teaching program. Eleven of the individuals were enrolled in a five-year Bachelor of Arts and Master of Teaching program (BA/MT) while four individuals were enrolled in a two-year post-graduate/master of teaching (PG/MT) program. The first two years of the BA/MT program focused on requirements for the bachelor degree for students' respective disciplines and included some general education courses. All participants enrolled in the same courses over a two-year period beginning with the fourth year for the BA/MT enrollees and during the first year for the PG/MT enrollees.

The course work specific to the learning and teaching of science began during the final two years of the BA/MT program and coincided with the PG/MT program course work. In fact the students from both programs intermingled in their courses and in their field-based experiences during these two years of the program.

The course work during these two years included educational psychology, special needs education, instructional technology, curriculum development, and assessment. Central to this research project was the four-credit secondary science methods course (taught by the fourth author of this paper) that spanned the two semesters preceding the final year of the combined programs. The participants in this study had just completed the four-credit series prior to student teaching. The course introduced preservice teachers to the theoretical and practical issues related to teaching science. The overall goal for the course was to prepare teachers capable of teaching a comprehensive view of science. Preservice teachers enrolled in the course were encouraged to view (and teach) science as a dynamic discipline composed of three interacting components: a) Science as a body of knowledge, b) Science as a set of processes, and c) Science as a way of knowing. This structure provided a framework for the topics and activities used throughout the course, which were regularly debriefed in regard to how they related to the body of knowledge, processes, and epistemology of science.

Of the three components, science epistemology (or way of knowing) is by far the least familiar to prospective science teachers in our teacher education program. Few, if any, of the preservice teachers who take the course have encountered any formal discussion or activities explicitly addressing this aspect of scientific knowledge. Preservice teachers in the course were introduced to the nature of science as a means of addressing science epistemology. Thus, one of the principal objectives of this course was to introduce the nature of science in a formalized and structured manner that provided a theoretical and practical framework for learning about, valuing, and teaching the nature of science.

The activities used to teach about the nature of science were similar to those used in several previous attempts to improve preservice teachers' understandings of the nature of science within science methods courses (e.g., Abd-El-Khalick et al., 1998; Bell et al., 2000; Akerson et al., 2000). These activities were gleaned from a variety of sources, including:

- *Teaching about Evolution and the Nature of Science* (National Academy of Sciences, 1998).
- *The Nature of Science in Science Education: Rationales and Strategies* (McComas, 1998).
- *Issues in Science Education: Professional Development Planning and Design* (Rhoton & Bowers, 2001).

The activity set included black box activities, discrepant events, inquiry activities, and readings, all designed to provide a springboard into discussions about targeted aspects of the nature of science. The presentation of the activities differed from that of previous studies in that additional emphasis was placed on teaching about aspects of the nature of science as an extension of process skills instruction. Many of the activities focused on making and distinguishing between observation and inference as the process skills portion of the lesson. Most of the activities were not content-specific, and thus could be taught in any science discipline.

Thus, in the "fossil activity" preservice teachers worked in pairs to make accurate sketches of fossil fragments provided by the instructor. Next, they were challenged to complete their sketches by inferring the rest of the organism and its environment and adding their inferences to the sketch using a different colored pen for emphasis. Finally, the preservice teachers made oral presentations about their inferred organisms in which they described its habitat, diet, and adaptations, as well as the factors upon which they based their inferences. During the presentation, the preservice teachers explicitly identified and distinguished between their observations and inferences. In concluding the activity, the instructor led a discussion about how the class had used their observations in combination with their own background knowledge to inform their inferences about the fossil organism, its niche, and environment. In order to make the instruction explicit, the instructor identified similarities between the process the class went through to complete their drawings and the work of paleontologists. This led to a reflective discussion on targeted tenets of the nature of science, including empirical base, creativity, subjectivity, and the myth of a single scientific method.

The final portion of the lesson distinguishes it most from the way researchers have previously used the activity. At this point, the instructor led the class through a metacognitive exercise in which they identified the process skill portion of the lesson and contrasted it with the nature of science portion of the lesson. Explicit attention was given to the differences between these types of instruction and the tendency for teachers to end the activity without teaching anything about the nature of science. The instructor emphasized how the nature of science provided a logical extension of the process skills-based activity and led a discussion on how the preservice teachers could use the activity in their own instruction to address both process skills and the nature of science.

This pattern of using engaging activities as a context for instruction about observation and inference, then extending the lesson to address relevant aspects of the nature of science was repeated throughout the two-semester secondary science methods course. The final debrief, in which the lesson was explicitly analyzed in terms of how it addressed both process skills and nature of science, was included each time. In all, the participants experienced 10 process skills-based nature of science activities.

Data Sources

The data collected for this project consisted of participant responses to questionnaires and interviews, artifacts from participant work (lesson plans and reflective journals), and observations of participants' teaching during internships. A primary source of data was Views of Nature of Science Form C (VNOS-C) questionnaire and interview protocol administered at the end of the two-semester science methods course sequence (May, 2004) and shortly after the end of the participants' semester-long student teaching experience, respectively. Information about the development, validity and administration of the VNOS-C may be found in Lederman et al. (2002). The questionnaires were coupled with interviews that followed up on participants' responses to the questionnaire. The VNOS-C questionnaire consists of 10 open-ended questions focusing on issues directly concerned with the nature of science framework adopted in the secondary science methods course (Appendix A). Data analysis began only after the student teaching experiences of the participants were completed. This postponement of any formal assessments of participants' nature of science-related knowledge and teaching practices served to reduce potential observer bias in regard to the observers "seeing" what they expected to see regarding the participants' instructional practices related to nature of science.

The exit interview was conducted shortly after participants' student teaching experiences. The fourth researcher, who served as instructor for the science methods course, did not conduct interviews or collect any other data in order to mitigate the possibility of participants' responding in ways that they anticipated the researcher would be more likely to approve. The goals of this interview were to validate and elaborate upon participants' VNOS-C responses, to assess the priority they ascribed to nature of science instruction, and to collect self-report data about nature of science lessons they taught during student teaching. The semi-structured interviews varied in length from 45 minutes to 75 minutes. Although a standard set of questions provided a framework for the interview (Appendix B), the interviewers made extensive use of follow-up questions to probe in greater depth into participants' thoughts and ideas as they were revealed during the interviews. In addition, the researchers asked questions specifically focused on the student teaching experiences and reviewed with participants their lesson plans addressing the nature of science. All the interviews were audiotaped and transcribed for later analysis.

Participants' self-reports about the nature of their instruction were triangulated with observational and lesson plan data. Collected lesson plans were comprehensive collections of all the lesson plans written and used by the 15 participants during their teaching experiences spanning 14 weeks of the Fall 2004 semester. In addition to the lesson plans, observational data were collected from university supervisors who were interviewed by the researchers weekly throughout the student teaching semester regarding their observations of the participants' nature of science instruction, based on both their written reports and their recollections.

The preservice teacher participants as a group selected the instrument to assess their pupils' understandings of the nature of science the semester prior to their student teaching experience. The preservice teachers completed the VNOS-C with its 10 questions during their methods course the previous spring semester and felt strongly that the instrument was too long, and that the reading level would be too advanced for some of their pupils. They anticipated that their pupils would be frustrated with its length and that their mentor teachers would not allow the time necessary to administer the VNOS-C. On the other hand, they were dissatisfied with the lack of detail provided by more easily administered forced-choice questionnaires. Consequently, they selected four questions from the VNOS-C that would address tenets of the nature of science they felt they would be most likely to teach during their student teaching semester; tentativeness, subjectivity, creativity, and the difference between theories and laws. Each participant administered the resulting open-ended response questionnaire (Appendix C) as a pretest at the beginning of the fall semester, 2004, and as a posttest approximately 12 weeks later at the end of the semester.

Data Analysis

The data sources were analyzed by the first, second, and third researchers in this investigation, none of whom were directly involved with the science teaching methods course. The researchers used analytic induction for this analysis (Bogdan & Biklen, 1992). The analysis comprised three primary tasks. The first analytical task began with the development of a thematic profile of the participants with regard to their personal understandings of the nature of science. Using the VNOS-C questionnaire and related follow-up interview responses, the researchers developed thematic profiles for each participant. These profiles were based on the participants' expressed understandings of each of the target characteristics of the nature of science listed previously in this paper. Once these profiles had been developed, each researcher returned to the data in an iterative fashion to search for disconfirming evidence. The profiles were then used to characterize each participant's understandings as *naïve*, *emergent* or *informed*, as per Lederman, Bell, Abd-El-Khalick, Schwartz, Lederman and Khishfe (2003). Participants in the naïve category expressed target understandings on fewer than five of the eight target characteristics of the nature of science, participants in the emergent category expressed target understandings on five to six of the characteristics, and participants in the informed category expressed target understandings on at least seven of the eight target characteristics. Prior to tackling the entire data set, the researchers' interpretations of a common data set were analyzed, compared, and re-analyzed in order to establish inter-rater agreement.

The second analytical task focused on the nature of science instruction utilized by the participants during their student teaching internships. The data used for this second section were the student teaching exit interviews and various relevant artifacts generated by the participants during their internships. These included written lesson reflections, university supervisors' observation notes, and lessons plans. For each participant, the researchers searched for references to the nature of science in each of these data sources. The researchers reviewed the lesson plans and observation notes for explicit references to the nature of science and whether these lessons featured new activities for teaching the nature or science or whether the participants were using activities learned through their science methods course. Particular attention was paid to whether the participants conflated the teaching of science process skills with the teaching of the nature of science. Finally, the researchers developed a nature of science pedagogical profile for each of the participants that included the participants' reported experiences from their interviews and corroborating evidence from their lesson plans and other artifacts. Again, inter-rater agreement on a common data set was established prior to analyzing the data in its entirety.

The third analytical task focused on pupil responses to the modified VNOS-C pre- and posttests. Once again using analytic induction, profiles for the pupils were developed to characterize targeted aspects of the nature of science for each question on the instrument. Because this shortened version did not assess all of the tenets addressed by the complete VNOS-C, and because the pupils' responses were less complete, it did not make sense to categorize their responses as naïve, emergent, or informed. Instead, pupil responses were categorized as "consistent" or "inconsistent" with the characterization of the nature of science presented earlier in this paper. Inter-rater agreement was established on a subset of pupil responses prior to analyzing the complete set.

Results

Preservice Teachers' Understanding of the Nature of Science

Of the 15 participants, 13 were characterized as having informed understandings of the nature of science, while 2 were classified as having emergent understandings of the nature of science. None of the participants were classified as having naïve understandings of the nature of science (Tables 3 and 4).

Table 3
Number of participants with "Informed" understandings of targeted tenets of the nature of science.

Tenet	Tenet Description	# of Participants w/ Informed Views
1. Tentative	All scientific knowledge is subject to change.	15
2. Empirical	Scientific knowledge is ultimately based on evidence.	15
3. Inference/Indirect Evidence	The development of scientific knowledge involves inferences as well as observations.	15
4. Nature of Theories	Scientific theories are well-substantiated and provide explanations.	13
5. Theories & Laws	Theories and laws are different but equally important.	12
6. Creativity	Creative thought permeates all scientific processes.	15
7. Subjectivity	Scientific knowledge is theory-laden in that it can depend on the theoretical perspectives of scientists, as well as their educational background and personal experiences.	15
8. Social & Cultural Influences	Scientific knowledge may be impacted by social and cultural influences.	15

Table 4
Assessment of participants' understandings of targeted tenets of the nature of science.

Participant	Tenets of which Participants Held Informed Understandings	Classification of Participants' Understandings
Christina	1,2,3,4,5,6,7,8	Informed
Hannah	1,2,3,4,5,6,7,8	Informed
Joanne	1,2,3,4,5,6,7,8	Informed
Kelly	1,2,3,4,5,6,7,8	Informed
Kendra	1,2,3,4,5,6,7,8	Informed
Lisa	1,2,3,4,5,6,7,8	Informed
Morgan	1,2,3,4,5,6,7,8	Informed
Rose	1,2,3,4,5,6,7,8	Informed
Eddie	1,2,3,4,5,6,7,8	Informed
Jane	1,2,3,4,5,6,7,8	Informed
Melissa	1,2,3,4,5,6,7,8	Informed
Monica	1,2,3,4,5,6,7,8	Informed
Erica	1,2,3,4,6,7,8	Informed
Maria	1,2,3,6,7,8	Emergent
Paula	1,2,3,6,7,8	Emergent

In order to be classified as having an informed view of the tentative nature of scientific knowledge, participants had to express the understanding that all scientific knowledge is subject to change (including scientific laws). All 15 of the participants expressed that scientific knowledge is tentative, as reflected in the following quotes.

> The body of knowledge that is science is ever changing. It's not stale like I had thought before. And it wasn't written by, entirely by dead white guys a century and a half ago. And that… it's not full of absolutes…it is seeking to answer those greater questions about the world around us. It's a way of probing and trying to make sense of the world around us, using the tools we have available to us.
>
> Hannah, Exit Interview

> I like bringing up nature of science when it is applicable to the content being discussed. For example, tying in nature of science ideas with the development of the theory of plate tectonics seemed to flow quite well. This was especially effective because my CI [mentor teacher] could tell the students that when he was in school no one accepted the theory of plate tectonics. This was a great way to confirm with the students that science is tentative and that new ideas are not always accepted when first presented to the scientific community.
>
> Kendra, Reflection

To be classified as holding an informed view of the empirical nature of science, participants had to indicate that scientific knowledge is based upon, and must be consistent with, empirical evidence. All of the participants stated in their VNOS-C responses or in their interviews that evidence is necessary when developing new scientific ideas (or in confirming existing ideas).

Consistent with their views of the tentative nature of science, all of the participants also acknowledged that evidence supports, rather than proves, scientific claims.

> Science is the study of the natural world. Science often differs from other ways of knowing in that it uses data and natural explanations for observed phenomena (as opposed to supernatural explanations – 'it's magic' or 'God did it').
>
> Jane, VNOS-C

> Even if the experiment confirms the hypothesis, this does not prove it, but just gives more evidence supporting it.
>
> Rose, VNOS-C

The third tenet of the nature of science was to understand the role that inference plays in the development of scientific knowledge. Inferences are possible interpretations based on observations. Each of the participants acknowledged the role of inferences and indirect evidence, thus all 15 were characterized as having informed views.

> There are tons of theories with plate tectonics and it is all indirect evidence that we have that supports these things, but it's pretty decent evidence. It's pretty widely accepted, but until we can slice the Earth in half and actually watch it happen, this is our best theory.
>
> Joanne, Exit Interview

> Scientists have gathered what they know about the atom from experimentation, observation, and inferences.
>
> Melissa, VNOS-C

Tenet four addresses the nature of scientific theories. In order to be classified as having an informed view of this tenet, participants had to express a sophisticated view of scientific theories, including such characteristics as: theories change either because of new evidence or because of new ways of looking at existing evidence, theories provide explanations, are well-substantiated, are based on inferences, and provide a framework for current knowledge and future investigations. Thirteen participants expressed conceptions of theories consistent with the above characterization and thus were classified as having informed views.

> Theories change because they are formed based on our best knowledge at the time. As technology advanced, we often develop better ways of getting at knowledge – i.e. telescopes and microscopes allowed us to directly observe many things which we couldn't see before. When this new knowledge is added to our previous knowledge, we often have to change our theories to better explain the phenomena.
>
> Jane, VNOS-C

> Theories tend to change over time, not because evidence is changing, necessarily, but because understandings about how that evidence should be interpreted changes or new evidence may be brought to light that deny the plausibility of previously accepted theories.
>
> Monica, VNOS-C

> A theory is the best idea we have based on a whole lot of data and years of study. A current theory provides a framework for understanding the world and can lead to new knowledge we might not have had otherwise.
>
> Morgan, Exit Interview

> Students need to understand that it's a scientific theory—it's not "only a theory." There's a lot of evidence to support [theories] and it's widely accepted. It is not a hypothesis or a guess or anything…
>
> Eddie, Exit Interview

The fifth tenet of the nature of science that we used in this study was the understanding that scientific theories and laws are different but equally important types of knowledge. A common misconception is that theories and laws are the same kinds of knowledge, but with differing amounts of supporting evidence. In this view, theories may become laws once they are proven (McComas, 1996). All the participants described originally possessing this naive view during the interview. To be characterized as "informed," the participants had to describe theories and laws as separate kinds of knowledge (in general, laws describe, while theories explain). Additionally, participants were required to contrast theories as based ultimately on inference, whereas laws are based ultimately on observations. Twelve participants expressed this sophisticated view of scientific theories and laws.

> A scientific law is often mathematical and is used to describe a pattern found in nature. A theory is used to try and explain the 'why' of a pattern or occurrence.
>
> Jane, VNOS-C

> A common misconception is that a law is a theory that has been proved true beyond a reasonable doubt – this is not true because science is tentative.
>
> Kendra, VNOS-C

> A scientific law is a statement describing how something works. A scientific theory attempts to explain something that cannot be directly observed. Laws are usually something that is observable. Theories are based on inference, they explain something.
>
> Eddie, Exit Interview

All 15 of the participants indicated that creativity is required in all aspects of scientific investigations. Additionally, 11 of these participants also expressed the understanding that there is no single scientific method.

> …conducting experiments doesn't mean that we follow the scientific method step by step process, that's a list of…that's a procedure that can be interchanged. So, I would say that maybe the scientific method is the structure that we can refer to when conducting an experiment, but it's not necessarily a set format of steps that we need to follow in order to have a successful experiment.
>
> Melissa, Exit Interview

The seventh targeted tenet of the nature of science in this study deals with the issue of subjectivity in science. To be classified as informed, participants had to understand that scientists are human and thus a level of subjectivity is present in all scientific endeavors. Additionally, the participants had to indicate that differences in data interpretation are due to the fact that scientists possess different backgrounds and ascribe to different theoretical frameworks, and that these differences actually can be viewed as strength, rather than a weakness. Furthermore, to be classified as “informed,” participants needed to express the understanding that science is not totally subjective—that in the end, scientific ideas have to be supported by evidence. All 15 participants expressed desired understandings of subjectivity in science.

> Science has to be based on evidence, but sometimes evidence is interpreted differently because of different cultural, religious, or educational backgrounds.
>
> Eddie, Exit Interview

> Though people may use the same evidence, different thoughts and ideas may come about depending on how each person interprets the data. This doesn’t mean that either of us is right or wrong about the picture, but based on our backgrounds and knowledge we have interpreted the picture differently.
>
> Rose, VNOS-C

> I think that you have to have evidence there so you definitely can’t just start making things up and…it has to be based on something but just because it is based on something doesn’t mean that personal opinion is not going to influence how you interpret that data.
>
> Melissa, Exit Interview

Finally, the eighth tenet addressed the importance of social and cultural influences in the development of scientific knowledge. Examples of informed responses include the influence of the church during the time of Galileo, the influence of the cold war during the space race between the United States and Russia, and the influence that funding has on the type of scientific research. All 15 participants held informed views of this tenet.

> In Galileo’s time, any theory of the universe that did not put Earth at the center was frowned upon because of the influence of the church in the secular world at that time…Science exists within the context of human nature and is thus influenced by it.
>
> Hannah, VNOS-C

> Cultural values also affect the scientific processes we choose to address. For example, the space race between the USA and USSR made the USSR focus on technologies and scientific ideas that they otherwise would have held stagnant in favor of testing scientific ideas meant to do things like feed people or cure disease.
>
> Monica, VNOS-C

> …funding is a serious issue in science. If something is not socially valuable, it often will not receive funding, and so research will not be done that could develop or change our model. When social and cultural views flat out conflicts with science and new ideas, things are often not presented to the public and science is not developed.

Jane, VNOS-C

In addition to these nature of science tenets addressed in the science methods class, 11 of the 15 participants also described sophisticated conceptions of experimentation. Specifically, they described experimentation as a formal process involving controlling of variables. Furthermore, they explained that the development of scientific knowledge does not rely solely on experimentation.

> There are many branches of science where experiments are not possible. One example is astronomy. Just because an astronomer cannot directly experiment on a star does not mean that there is no scientific knowledge in astronomy. Scientists can develop knowledge through observations.
>
> Hannah, VNOS-C

In summary, all but 2 of the participants expressed informed understandings of the targeted aspects of the nature of science. Although these 2 held onto naïve conceptions of the relationship between theories and laws, their overall understandings of science as a human enterprise, its tentative and self-correcting nature, and the role of creativity in each stage of a scientific investigation provided a foundation for them to accurately teach about these aspects of the nature of science in their own classrooms.

Classroom Instruction on the Nature of Science

The previous section indicated that the participants generally possessed informed views of the nature of science that could potentially provide the foundation for explicit and reflective nature of science instruction to their pupils. The next task was to determine whether the participants' instruction during student teaching reflected their informed understandings of the nature of science. To this end, observation notes, lesson plans, reflections, and exit interviews showed that all of the participants addressed the nature of science during their student teaching using a variety of activities (Table 5). Most of the participants taught a unit on the nature of science at the beginning of the year and then went on to periodically address specific tenets throughout the rest of their student teaching. The tenets addressed most often by the participants were that science is empirical, tentative, can be based on inference or indirect evidence, and is subjective. Participants also addressed the nature of, and differences between, scientific theories and laws. Overall, the 15 participants taught a total of 76 nature of science lessons with each participant averaging about 5 nature of science lessons. While all of the participants utilized nature of science activities demonstrated in the science methods class, twelve participants taught a total of 19 nature of science activities that they had found or developed themselves. The following examples describe some of the activities utilized by the participants.

Table 5
Nature of science activities and tenets

Name	Activities		Nature of Science Tenets	Source of Activity
1. Christina	Candle Observation	→	Inference/indirect evidence, empirical	Methods Class
	More Lunar Lunacy	→	Inference/indirect evidence, empirical, tentative	Other

	Mystery Tube	→	Inference/indirect evidence, theories & laws	Methods Class
	Nature of Science PowerPoint	→	Tentative, theories & laws, creativity, subjectivity, social & cultural influences	Other
	Unit Test	→	Theories & laws	Original
	Explicit Discussions	→	Tentative, nature of theories	Original
2. Eddie	Hindsight is 20/20	→	Subjectivity	Methods Class
	Mystery Tube	→	Inference/indirect evidence, theories & laws	Methods Class
	Dwarf Human Ancestors	→	Inference/indirect evidence, empirical, tentative	Other
	Falling Object Lab	→	Theories & laws	Other
3. Erica	Mystery Tube	→	Inference/indirect evidence, theories & laws	Methods Class
	Dust Bowl	→	Inference/indirect evidence, empirical	Other
	Candle Observation	→	Inference/indirect evidence, empirical	Methods Class
	Fossil Footprints	→	Inference/indirect evidence, empirical, subjectivity	Methods Class
	Newspaper articles	→	Tentative	Other
	Explicit Discussion	→	Theories & laws	Original
4. Hannah	Candle Observation	→	Inference/indirect evidence, empirical	Methods Class
	"The Princess Bride"	→	Inference/indirect evidence, empirical	Original
	Comic Strips	→	Inference/indirect evidence, empirical, tentative	Methods Class
	Mystery Tube	→	Inference/indirect evidence, theories & laws	Methods Class
	Rotational Inertia	→	Inference/indirect evidence, empirical	Other
	Explicit Discussions	→	Theories & laws, tentative	Original
5. Jane	Nature of Science PowerPoint	→	Inference/indirect evidence, empirical, tentative, theories & laws, subjectivity, creativity	Other
	Candle Observation	→	Inference/indirect evidence, empirical	Methods Class
	Hindsight is 20/20	→	Subjectivity	Methods Class
	Fossil Footprints	→	Inference/indirect evidence, empirical, subjectivity	Methods Class

	Layers and Convections	→	Inference/indirect evidence, empirical, tentative	Other
	Bathymetric Discovery	→	Inference/indirect evidence, empirical, tentative	Other
6. Joanne	Fossil Fragments	→	Inference/indirect evidence, empirical, creativity	Methods Class
	GIS and Earthquakes	→	Empirical, theories & laws	Other
	Seismic Waves activity	→	Theories & laws, empirical, inference/indirect evidence	Other
	Candle Observation	→	Inference/indirect evidence, empirical	Methods Class
	Mystery Tube	→	Inference/indirect evidence, theories & laws	Methods Class
	Can of Cashews	→	Inference/indirect evidence, empirical, tentative, subjectivity	Other
	Explicit Discussions	→	Theories & laws, empirical	Original
7. Kelly	Candle Observation	→	Inference/indirect evidence, empirical	Methods Class
	Fossil Footprints	→	Inference/indirect evidence, empirical	Methods Class
	What is Life?	→	Inference/indirect evidence, empirical, subjectivity	Other
	Chemistry – Microscopes	→	Inference/indirect evidence, empirical, tentative	Other
8. Kendra	Candle Observation	→	Inference/indirect evidence, empirical, subjectivity, tentative	Methods Class
	Comic Strips	→	Inference/indirect evidence, empirical, tentative	Methods Class
	Minerals Test	→	Inference/indirect evidence, empirical, tentative	Original
	Plate Tectonics Test	→	Inference/indirect evidence, empirical	Original
	Explicit Discussions	→	Social & cultural influences	Original
9. Lisa	Candle Observation	→	Inference/indirect evidence, empirical, tentative	Methods Class
	Cans	→	Inference/indirect evidence, empirical, tentative	Methods Class
	Fossil Footprints	→	Inference/indirect evidence, empirical, tentative, theories & laws	Methods Class
	History of Periodic Table	→	Tentative	Other
	Cow picture	→	Inference/indirect evidence,	Methods Class

			empirical, subjectivity	
10. Maria	Candle Observation	→	Inference/indirect evidence, empirical, tentative	Methods Class
	Geometric Drawing	→	Subjectivity	Other
	Mystery Tube	→	Inference/indirect evidence, empirical, theories & laws	Methods Class
	Comic Strips	→	Inference/indirect evidence, empirical	Methods Class
	Fossil Fragments	→	Inference/indirect evidence, empirical	Methods Class
11. Melissa	Mystery Tube	→	Inference/indirect evidence, empirical, tentative, nature of theories	Methods Class
	Cell Theory	→	Tentative, nature of theories, empirical, subjectivity	Other
	Candle Observation	→	Inference/indirect evidence, empirical, tentative	Methods Class
	Explicit Discussions	→		Original
12. Monica	PowerPoint lesson	→	Inference/indirect evidence, empirical, tentative, theories & laws	Other
	Fossil Footprints	→	Inference/indirect evidence, empirical	Methods Class
	Princess Bride	→	Inference/indirect evidence, empirical	Original
	Maps	→	Tentative	Other
	Rock Identification	→	Inference/indirect evidence, empirical, tentative, creativity	Other
	Unit Test	→	Inference/indirect evidence, theories & laws	Original
13. Morgan	Bean Plant activity	→	Inference/indirect evidence, empirical, subjectivity	Other
	Tater Tots	→	Tentative, creativity	Other
	Inheritance and Karyotyping	→	Inference/indirect evidence, empirical	Other
14. Paula	Comic Strip	→	Inference/indirect evidence, empirical, tentative, subjectivity	Methods Class
	Fossil Footprints	→	Inference/indirect evidence, empirical, tentative, subjectivity	Methods Class
	Mystery Tube	→	Inference/indirect evidence, empirical, tentative	Methods Class

	Study of Natural Causes	→	Empirical, tentative	Other
	Explicit Discussion	→	Theories & laws	Other
15. Rose	Candle Observation	→	Inference/indirect evidence, empirical, subjectivity	Methods Class
	Comic Strip	→	Inference/indirect evidence, empirical	Methods Class
	Classification Systems	→	Tentative, empirical	Other

The “Candle Observation” activity is an example of an activity that participants saw modeled in the science methods class. Eleven out of 15 participants incorporated this activity into their nature of science units. Typically, participants started the activity by lighting the “candle” and asking students to make observations. The “candle” was made of string cheese, and an almond sliver (Figure 1). After students made their observations, the teacher took a bite out of the “candle” and asked students to make some more observations. By this point, the majority of students figured out that the “candle” was not a candle at all. The teachers used this activity to introduce the importance of inference in science, and how preconceived ideas can influence observations.

> This demonstration (candle activity) provided a discrepant event to begin a discussion about observation, inference, and the tentative nature of scientific knowledge. This activity demonstrated the tentative nature of scientific knowledge because students saw how their beliefs about the candle changed as they made further observations.
>
> Hannah, Exit Interview

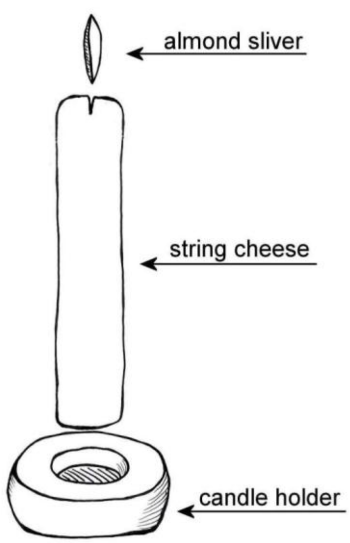

Figure 1. The “string-cheese” candle.

Some of the participants also introduced the concept of subjectivity to their students using the candle observation activity. For example, Rose explained “I also asked students to explain why they thought I was holding a candle, and talked about how our background or previous knowledge has a great influence on our thinking (Rose, Exit Interview)."

Another popular activity that the participants adapted from the methods course was the "Mystery Tube" activity (National Academy of Sciences, 1998). Eight participants included it in their nature of science units. The activity started with students making observations of the Mystery Tube, which was made using a section of mailing tube and strings. The mailing tube was sealed on both ends and the strings were sticking out of the tube in four places (Figure 2). After students made their initial observations, the teacher asked if it was possible to determine how the tube was constructed on the inside to make it behave as they had observed. Students generally suggested pulling on one of the strings. Students were asked to make more observations and to also predict what would happen when the teacher pulled on a particular string. After the second round of observations, students were asked to infer what was inside of the tube using the observations they made and to either draw or construct a model based on their inferences. The teachers used this activity to discuss models, the roles of both observations and inferences in the development of scientific knowledge, the difference between theories and laws, and tentativeness in science. As Paula explained,

> The mystery tube activity demonstrated that scientists cannot always make direct observations and they must use indirect evidence to explain how something works and construct a model. This led into an interactive discussion about how scientists use models to explain a particular concept, for example, the interior of an atom or the earth.
>
> Paula, Exit Interview

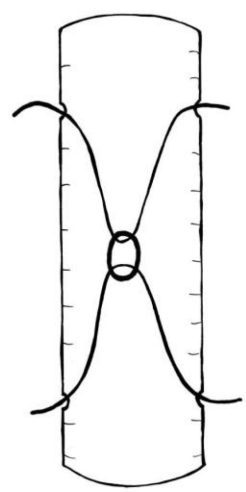

Figure 2. The mystery tube.

Many of the participants taught nature of science activities that they had found or developed themselves. For example, Monica developed and shared a lesson with Hannah on the importance of evidence gathered by observations and inferences and the inferential nature of theories. Monica put together a series of familiar video clips from the movie "The Princess Bride" as a way to get her students more involved. The clips showed Prince Humperdink using footprints and other clues from the surrounding environment (observations) to construct an explanation about what had previously occurred at each of several battle scenes (inferences). The teacher stopped the clip after each segment and discussed with her students whether or not Prince Humperdink's theories would hold up if a scientist demanded evidence. The debriefing included a discussion on the importance of evidence in science, the inferential nature of theories, the tentativeness of science, and the role of creativity in science.

Joanne developed an original black-box activity called "can of cashews" to address the importance of direct and indirect evidence, tentativeness, and subjectivity. Students were given sealed cashew cans containing unknown objects. The students were asked to make observations and infer what was inside the cans without looking in them. Once each group had completed these tasks, Joanne opened the cans to show students that the cans contained both metal nuts and confetti. All of the groups successfully identified the metal nuts, but none of the groups determined that confetti was also in the cans. "The purpose of using confetti in the cashew can was to illustrate that in science, because we don't have direct evidence of something, doesn't mean that it doesn't exist (Joanne, Exit Interview)." Joanne connected this activity to scientific examples such as the interior of the Earth.

Many of the participants incorporated explicit references to the nature of science into more typical science lessons. For example, Joanne discussed the differences between theories and laws and the tentativeness of scientific knowledge at the end of an earthquake lab in her earth science class. Morgan taught the importance of evidence in science during a post-lab discussion on Inheritance and Karyotyping in her biology class. Jane addressed the importance of observation and inference in the development of scientific knowledge at the conclusion of a lab on convection currents in the ocean.

> We discussed the fact that we could observe those things (movement of food coloring in water and movement of popsicle sticks on the surface), but in order to find out what was going on, we would have to make inferences—how water is rising, moving out from the center, and pushing the popsicle sticks. The students understood that both phases of gathering information were necessary, and that the same principles applied to discovering information about convection in the asthenosphere—we can't directly measure it, but we have a good working model.
>
> Jane, Nature of Science Reflection

Eight participants explicitly addressed the nature of science in class warm-ups. For example, Erica used an article about the discovery of ancient human remains on a Pacific island to address tentativeness and subjectivity.

> The new discovery (of human skulls) has changed some aspects of the knowledge of human evolution which reinforced the fact that scientific knowledge changes with new information. The article also discussed the fact that scientists are disagreeing on how to classify the newly discovered skulls. Some students were able to explain that some of the observations in the article were actually inferences. This gave students a real life example of some of the aspects of the nature of science that we discussed in class.
>
> Erica, Exit Interview

The majority of the participants provided both formative and summative assessments of their pupils' understandings of the nature of science. The most common summative assessment was nature of science-related multiple-choice questions on the unit exam. Monica provided the most complete assessments of her students' understandings of the nature of science, including forced-choice questions and open-ended questions on her formative and summative assessments. Examples of her open-ended questions include:

1. Explain the difference between a Scientific Law and a Scientific Theory.
2. Can one set of data or evidence be used to explain more than one theory? Why or why not?
3. Can a THEORY ever turn into a LAW?

When asked during the exit interviews whether their pupils learned anything about the nature of science, several participants indicated that they thought their pupils learned quite a bit. For example, Erica reported that her students learned five specific aspects of the nature of science.

> The students understood that individuals think differently and therefore solve problems differently. A scientist's previous knowledge, past experiences, and imagination all affect his interpretation of evidence. The students seemed to understand that scientific knowledge changes as scientists gather information and evidence. I think that students really learned to differentiate between observation and inference as process skills and they know that scientists use both to develop knowledge. Most of my students could tell you how scientists used creativity to design an experiment, but they might not come out and say that scientists use creativity in new ideas for experiments, interpreting data, etc.
>
> Erica, Exit Interview

A majority of the participants indicated that their pupils learned about some aspects of the nature of science, but not as much as they had expected.

> I think that they improved over the course of the semester, but they didn't take away as much as I wanted them to. So, yeah, I think there was a slight improvement. It seemed like they were leaning towards certain ideas but looking over their answers it became obvious that the still didn't have a good, firm grasp on what the nature of science was or if they did they didn't know how to communicate that on that test.
>
> Melissa, Exit Interview

> I feel like I was successful in bringing awareness to the nature of science, but I don't really think the kids remembered much about it beyond the instructional unit, despite mentioning it over and over again in classroom discussion.
>
> Joanne, Nature of Science Reflection

Finally, a few indicated that their pupils did not learn much about the nature of science. When asked why they thought this was the case, these participants responded that pressure to cover content prevented them from teaching as much about the nature of science as they would have liked. Others indicated that the limited amount of time they were able to devote to nature of science instruction was not enough to change their pupils' conceptions.

> I feel like they got something from [my nature of science lessons], but I don't feel like their answers on the nature of science surveys changed. I think having me present for a

> couple of days about these concepts isn't necessarily going to erase what they might have already come into my class with.
>
> Monica, Exit Interview

In summary, much of the participants' nature of science instruction occurred at the beginning of the semester and primarily focused on the importance of evidence, the roles of observation and inference, the tentativeness of scientific theories and laws, and the role of subjectivity in the development of scientific knowledge. However, several participants taught other aspects of the nature of science and many revisited the nature of science throughout the semester. Overall, the participants explicitly taught all eight of the nature of science tenets addressed in the science methods class. Many of the participants provided formal assessments of their pupils' understandings of the nature of science in addition to the modified VNOS-C used to measure gains in pupil understandings for this investigation. Nearly all of the participants believed that their pupils learned about the nature of science from their instruction, although they also expressed the belief that their pupils had much more to learn.

Pupil Results

The final phase of the investigation involved assessing what pupils learned from the preservice teachers' nature of science instruction. Selection for this portion of the study was based on a) willingness of the preservice teacher to participate in this phase of the study, b) willingness of their mentor teacher to participate, and c) willingness of the class to participate as reflected by an IRB consent form return rate of at least 50% from pupils and their parents. Application of these criteria resulted in one class for each of four of the preservice teacher participants (Table 6).

Table 6
Characteristics of classes selected for assessment of pupil understandings.

Preservice Teacher	Course Taught	Academic Level	Class Size	Sample Size
Kendra	Earth Science	Honors	18	11
Hannah	Physics	Honors	26	24
Christina	Earth Science	Advanced	24	16
Jane	Astronomy/ Oceanography	Advanced	37	19

As previously stated, the preservice teachers in this study administered a modified version of the VNOS-C to evaluate their pupils' understandings of the nature of science. Each question was designed to elicit responses targeting a specific nature of science tenet.

Question 1 probed pupils for their ideas about the role of indirect evidence and inferences in science, and the tentative nature of science. Before instruction, pupils typically had very absolute understandings about scientific knowledge, as indicated by such responses as "scientists are very positive" about the structure of the atom, and that they have "powerful microscopes or other devices to magnify the atoms" to see them.

Question 2 asked pupils about their knowledge of the function and relationship of theories and laws. Prior to instruction, pupils typically stated that theories are "opinions, ideas, guesses, or beliefs" while laws are "facts, proven, or accepted by all." Pupils tended to see theories as something scientists are still testing, and that they can turn into laws once they have been proven. They generally did not see how theories and laws are two distinct ways of describing scientific knowledge.

Question 3 elicited pupils' ideas about the roles of creativity and imagination in the development of scientific knowledge. Before instruction on the nature of science, pupils ascribed some role for creativity in science, but generally limited creativity to the design of investigations. They had trouble seeing how creativity and imagination permeate the whole scientific endeavor.

Question 4 assessed understandings of subjectivity in science, especially in regard to the role of cultural and social influences. The question asked pupils to explain why scientists disagree about the cause of dinosaur extinctions even when presented with the same information. Before nature of science instruction, pupils typically answered that "it was such a long time ago, no one was there," or "no one really knows what happened." They failed to describe how differences in background and theoretical commitments could lead different groups of scientists to interpret the same evidence in different ways.

Kendra's earth science class.

Kendra taught two honors level, one advanced level, and two standard level ninth grade earth science courses at a local county high school. Her mentor teacher had a Ph.D. in geology and had worked as a geology consultant prior to becoming a science teacher. Although he did not explicitly teach about the nature of science himself, he supported Kendra's efforts to do so. As previously reported, Kendra possessed informed understandings of all of the targeted nature of science tenets. She taught a total of six explicit nature of science lessons. In these lessons, she explicitly addressed the tentative nature of science, the importance of scientific evidence, the role of inference/indirect evidence, the roles of creativity and subjectivity in the development of scientific knowledge, and the impact that society and culture can have on the development of scientific knowledge.

The class for which we report pupil results was made up of 18 pupils with 11 agreeing to participate in the study (61%). Of the preservice teachers who participated in this part of the investigation, Kendra's pupils achieved the highest posttest scores (Table 7). Her pupils achieved substantial gains on questions 1, 3, and 4, which dealt with tentativeness, creativity, and subjectivity, respectively. These results matched well with Kendra's explicit nature of science instruction (see Table 4). Pupil gains for the differences between scientific theories and laws were much less impressive. However, as reported in the previous section, Kendra did not include explicit instruction about this tenet of the nature of science, so these results are not surprising.

Table 7
Kendra's pre- and posttest pupil results.

Preservice Teacher: Kendra	Question	Nature of Science Tenet	Pretest Desired Responses (%)	Posttest Desired Responses (%)
	1	Indirect evidence and	27.3	81.8

	tentativeness		
2	Theories and Laws	0	9.1
3	Creativity and Imagination	45.5	90.9
4	Subjectivity	45.5	72.7

Table 8 contains representative quotes from pupils in Kendra's class who made substantial gains in their understandings about the nature of science. The pairs of quotes are matched so that they demonstrate the changes in understandings for the same pupil over the course of the semester.

Table 8
Quotes from Kendra's pupils.

Question	Pre-Quote	Post-Quote
1	"Because of the technology that we have today, scientists can be most certain about what an atom looks like. Scientists probably can get photographs of an atom from a very strong microscope."	"Scientists are very certain about the structure of the atom; however, since no one has actually seen it, it isn't fully proven. Scientists use observations and inferences to determine what it looks like."
4	"Humans will always have disagreements and controversy because it is human nature. Also, every person is different and have their own beliefs."	"We all have different minds, background experiences. People have different backgrounds and that changes the way they look at things."

In both sets of quotes, it is clear that the pupils' posttest responses reflected understandings that were more tentative and/or more sophisticated. The pupil quoted for question 1 changed his/her understanding of how scientists know about the structure of the atom from an absolute view emphasizing direct observation to a more tentative view that recognizes the role of indirect evidence and leaves open the possibility for change. In the second pair of quotes, the pupil moved from a naïve view that scientific controversies simply result from differences in beliefs to a more sophisticated view that such controversies can result from differences in scientists' background experiences.

When Kendra was presented with these results, she was impressed that her pupils' overall understandings of the nature of science improved even though her nature of science instruction was concentrated at the beginning of the school year. She recognized the importance of teaching the nature of science explicitly and acknowledged that she had not done so in regard to the differences between scientific theories and laws. Overall, she was confident that explicitly teaching the nature of science was beneficial for her pupils and that she will make it a point to include the nature of science in her future classes.

Hannah's Physics Class

Hannah taught four honors level and one standard level physics class to tenth through twelfth grade pupils. Her mentor teacher was a very experienced physics teacher with a strong reputation as one of the top physics teachers in the county. While he did not explicitly teach about the nature of science before working with Hannah, he was supportive of her efforts to incorporate the nature of science in her classroom instruction. In fact, he confided to one of the researchers that seeing Hannah teach the nature of science caused him to reflect on his own instruction and revise the way that he taught physics. As previously reported, Hannah possessed informed understandings of all of the targeted nature of science tenets. She developed and taught a unit on the nature of science that included six lessons. In these lessons, she explicitly addressed the tentative nature of science, the importance of scientific evidence, the role of inference/indirect evidence, and the differences between scientific theories and laws.

The honors class selected for this portion of the study was made up of 26 pupils with 24 agreeing to participate (92%). Hannah's pupils' responses to the modified VNOS-C questionnaire reflected substantial gains in three of the four questions (Table 9). As opposed to Kendra's pupils, Hannah's pupils improved their understandings of scientific theories and laws, a topic she addressed explicitly in one of her lessons. Pupils made gains in their understandings of tentativeness, creativity, and subjectivity, but not to the same degree as for scientific theories and laws.

Table 9
Hannah's pre- and posttest pupil results.

Preservice Teacher: Hannah	Question	Nature of Science Tenet	Pretest Desired Responses (%)	Posttest Desired Responses (%)
	1	Indirect evidence and tentativeness	62.5	75
	2	Theories and Laws	8.3	62.5
	3	Creativity and Imagination	37.5	41.7
	4	Subjectivity	29.2	45.8

Table 10 contains paired pupil responses for the pre- and posttests for Hannah's class. Again, the pairs of quotes are matched so that they demonstrate changes in understandings for the same pupil over the course of the semester.

Table 10
Quotes from Hannah's pupils.

Question	Pre-Quote	Post-Quote
2	"A scientific law is something that is accepted to be accurate. Theories are general assumptions that have not yet been proven to be universally the case."	"A scientific theory explains why a certain thing occurs. A scientific law explains what occurs."
4	"They disagree – there is no first hand source of the event and no tangible evidence to support each theory."	"One would look at [the evidence] from a geological point of view and the other would look at it from a Darwin point of view. They look at it different ways. They have different beliefs, different

fields they know more about."

In these sets of quotes, it is clear that the pupils' understandings changed over the semester. The pupil quoted for question 2 changed his/her view of theories and laws. Prior to instruction, the pupil viewed laws as accepted knowledge and theories as something that has not been proven. The pupil's posttest response showed that he/she recognized that theories and laws are different types of knowledge with different purposes and no longer indicated that laws are more absolute than theories. In the second set of quotes, the pupil originally thought that without direct observation, there can be no conclusions in science. However, after nature of science instruction, this pupil's understanding shifted to include that different scientific background influence subjectivity in science.

When Hannah evaluated these results, she was not satisfied. Hannah expected her pupils' understanding of the nature of science to improve, primarily because of how her nature of science lessons were received. She described how her pupils enthusiastically participated in the activities and demonstrated their understandings during class discussions prior to completing the post questionnaire. Even though her pupils' responses reflected improvement in all four questions, Hannah believed that there was much room for improvement. Thus, she described her plans to integrate nature of science instruction into physics content throughout the year, rather than only at the beginning of the school year.

Christina's Earth Science Class

Christina taught three advanced earth science courses at a local urban high school. Her mentor teacher had several years experience teaching middle school science, but had only taught earth science at the high school level for one year. While he did not oppose Christina's efforts to teach the nature of science, he tended to interrupt these lessons, and at times he contradicted her in front of the class. As previously reported, Christina possessed informed understandings of all of the targeted nature of science tenets. She taught a total of five explicit nature of science lessons. In these lessons, she attempted to address all of the nature of science tenets she learned during the methods classes.

The class that participated in this study was made up of 24 pupils with 16 agreeing to participate (67%). Christina's pupils made positive gains in their understandings of the difference between scientific theories and laws and the roles of creativity and subjectivity in science (Table 11). However, their understandings of the tentativeness of science actually appeared to decrease over the course of a semester.

Table 11
Christina's pre- and posttest pupil results.

Preservice Teacher: Christina	Question	Nature of Science Tenet	Pretest Desired Responses (%)	Posttest Desired Responses (%)
	1	Indirect evidence and tentativeness	43.8	37.5
	2	Theories and Laws	18.8	43.8

3	Creativity and Imagination	31.3	37.5
4	Subjectivity	37.5	50

The paired quotes in Table 12 are representative of the views held by Christina's pupils at the beginning and end of her student teaching semester.

Table 12
Quotes from Christina's pupils

Question	Pre-Quote		Post-Quote
1	"High powered microscopes and pictures of what they see."	no change →	"Looking in a microscope."
3	"I think they do at the very restricted extent. Their creativity is limited since they are dealing with facts and laws… they don't just get to use their imagination…"	desired change →	"I think they have to use creativity to some extent, but they have to follow their methods and many rules as well. They have to be open to new ideas and use creativity to think of all possible explanations for things."

These sets of quotes represent the dichotomy of Christina's pupils' understanding of the nature of science. While many of her pupils progressed in their understandings of the nature of science, others tended to hold on to naïve views. For example, the pupil quoted for question 3 articulated a broader, less restricted view of the role that creativity plays in the scientific process. On the other hand, even after instruction, the pupil quoted for question 1 held on to the view that the structure of the atom is determined through direct observation.

Christina was not surprised by her pupils' results, especially in regard to the tentative nature of science. In her reflection she discussed that throughout her nature of science instruction, some of her pupils questioned the concept that there is no absolute knowledge in science. She partially attributed these negative results to the fact that her mentor teacher openly disagreed with her during some of her nature of science lessons. She speculated that this created skepticism on the part of her pupils. In fact, she quoted one pupil as saying, "according to you, nothing in science is proven, but we both know that's wrong."

Jane's Oceanography/Astronomy Class

Jane taught two advanced level oceanography and astronomy classes to twelfth grade pupils at a rural high school. Jane's classes were by far the largest in the study (mean = 34 pupils). Her mentor teacher was the chair of the science department and had many years of teaching experience. Although Jane's mentor teacher was very supportive of her efforts to teach about the nature of science, the mentor teacher occasionally taught lessons that contradicted what Jane had taught. As previously reported, Jane possessed informed understandings of all eight of the targeted nature of science tenets. She taught a total of six explicit nature of science lessons. In these lessons, she made an effort to address all of the nature of science tenets she learned during the methods classes.

The class selected for participation in this study was made up of 37 pupils with 19 agreeing to participate (51%). Of all of the participants in this study, Jane's pupils achieved the lowest percentage of desired understandings (Table 13). However, it is important to note that the pupils in this elective class also started out with the lowest percentage of desired understandings. Pre- to posttest gains were substantial for each question.

Table 13
Jane's pre- and posttest pupil results.

Preservice Teacher: Jane	Question	Nature of Science Tenet	Pretest Desired Responses (%)	Posttest Desired Responses (%)
	1	Indirect evidence and tentativeness	15.8	31.6
	2	Theories and Laws	5.3	26.3
	3	Creativity and Imagination	10.5	31.6
	4	Subjectivity	21.1	36.8

Table 14 shows paired quotes from Jane's pupils representing their understandings of the nature of science including one example of an improved understanding and one example of a pupil who's understandings of a tenet of the nature of science did not change.

Table 14
Quotes from Jane's pupils.

Question	Pre-Quote		Post-Quote
2	"Scientific theory is proven many times but not solid. Scientific law is one step further than scientific theory in credibility."	desired change →	"A law explains mathematically how something works. A theory explains why something works."
3	"They use creativity by thinking of ways to experiment and building new things."	no change →	"Yes, because you have to have [creativity and imagination] to come up with experiments."

The pupil quoted in question 2 moved away from the naïve view that theories and laws have a hierarchical relationship to a view that theories and laws represent different kinds of knowledge. The pupil quoted in question 3 did not seem to progress beyond the view that creativity solely exists in the process of developing an experiment.

After reading her pupils' posttest response, Jane was pleasantly surprised. Even though the posttest scores were not as high as she had hoped, she was encouraged to see that many of the pupils had made some progress. As she explained, "Considering that these pupils were seniors who had been taught one thing their entire lives, and I only had a couple months to change it, the fact that there was any improvement at all means there is hope." She commented that the lack of space for this class of 37 pupils created an extremely challenging learning environment.

Overall Pupil Results

Table 15 provides a summary of the combined results for all of the participating pupils (n = 70). The validity of combining these data is somewhat artificial, due to the fact that the four teachers were free to choose their own objectives and approaches to nature of science instruction. Some obviously emphasized certain tenets more than others. Still, the combined results present a rough picture of what the pupils learned about the nature of science from the preservice teachers. Pre- to post-instruction gains were substantial, ranging from 15.7% to 31.4%. The greatest gains were for question 2 on theories and laws, which demonstrated an overall gain of 31.4% of the participants expressing informed views. On the other hand, the post-instruction results indicate that less than half of the pupils had obtained informed views on three of the four nature of science tenets addressed in the preservice teachers' nature of science instruction.

Table 15
Overall pre- and posttest pupil results.

Question	Nature of Science Tenet	Pretest Desired Responses (%)	Posttest Desired Responses (%)	Percentage Point Gain
1	Indirect evidence and tentativeness	40.0	55.7	15.7
2	Theories and Laws	8.6	40.0	31.4
3	Creativity and Imagination	30.0	45.7	15.7
4	Subjectivity	31.4	48.6	17.2

Discussion and Implications

A recent investigation using a process skills-based approach to nature of science instruction has shown promise in facilitating preservice teachers' understandings of, and abilities to teach, the nature of science (Bell et al., 2005). This approach to nature of science instruction involves inquiry activities, analogies, episodes from the history of science, and explicit instruction involving the following key elements:

1. Linking the unfamiliar and abstract concepts of the nature of science to more familiar and concrete process skills instruction.
2. Explicitly delineating between the portions of lessons and activities focusing on process skills and those addressing the nature of science.
3. Modeling the process skills-based approach to nature of science instruction using activities that the preservice teachers could readily envision using themselves.
4. Providing preservice teachers with opportunities to develop instructional activities and to teach lessons utilizing the process skills approach to nature of science instruction.

In the present investigation, we assessed the impact of process skills-based nature of science instruction on a second cohort of preservice teachers' nature of science understandings and instructional practice. Additionally, we explored the impact of these preservice teachers' nature of science instruction on their pupils' understandings. The investigation was designed to answer three specific questions:

1. What is the impact of the process skills-based approach on secondary preservice teachers' understandings of the nature of science?
2. What is the impact of the process skills-based approach on secondary preservice teachers' instructional practice during student teaching?
3. What is the impact of secondary preservice teachers' instructional practice about the nature of science on pupil learning?

Participants in this study were enrolled in a year-long science methods course and learned about the nature of science through process-skills based instruction. By the end of the methods course, all of the participants had achieved informed understandings on the majority of aspects of the nature of science addressed in the science methods class. Combined with the findings of the Bell et al. (2005) study, these results provide a degree of confirmation of the effectiveness of process skills-based nature of science instruction. The posttest-only assessment of the preservice teacher participants' understandings leaves open the possibility that they learned achieved desired understandings from experiences outside of the science methods class. However, we believe that this is unlikely, given the results of previous assessments of preservice teachers' understandings of the nature of science (Abd-El-Khalick & BouJaoude, 1997; Duschl, 1990; Lederman, 1992; Pomeroy, 1993). Additionally, it is important to note that when asked in their exit interviews where they learned specific aspects of the nature of science, the preservice teachers all specifically referred to the science methods course.

In light of these findings and the aforementioned research, we chose not to administer the VNOS-C as a pretest in order to avoid the possibility of it becoming a treatment in itself (as in Bell et al., 2003). Furthermore, we wanted to model appropriate nature of science instruction by allowing their understandings about the nature of science to grow throughout the methods class. Consequently, we postponed using the VNOS-C until the end of the course to avoid prematurely alerting the preservice teachers about what they would learn later in the course. Regardless of the ultimate source of their developed nature of science understandings, the results of the VNOS-C posttest demonstrated that they had an appropriate foundation for teaching about the nature of science.

Postponing the administration of the VNOS-C until the end of the course allowed for another, unintended comparison to the results of a recent investigation concerning the stability of preservice teachers' newly acquired understandings of the nature of science. Akerson et al. (2006) concluded that a single course may be insufficient for producing lasting change in preservice teachers' conceptions of the nature of science. Many of the participants in their study had reverted back to their naïve views as early as 5 months after participating in "explicit reflective" nature of science instruction. The nature of science instruction in the present investigation occurred during the two-semester science teaching methods course sequence. Most of this instruction occurred during the fall semester, although the concepts of subjectivity and cultural influences were addressed in January of the spring semester. The VNOS-C was administered at the end of the spring semester—3 months after the final nature of science lesson, and as many as 7 months after many of the nature of science concepts had been taught. Thus, the administration of the VNOS-C in the present investigation can be viewed as an assessment of long-term retention. The results indicated that participants retained desired understandings many months after experiencing the process skills-based approach. Furthermore, to the degree that their planning, instruction, and reflective writings during student teaching reflected their conceptions of the nature of science, they retained targeted conceptions for more than one year after they had learned these conceptions in the science teaching methods courses.

In regard to nature of science instruction, the participants taught at least 3 and as many as 10 specific nature of science lessons over the course of their student teaching experience. This compares favorably to previous studies (Abd-El-Khalick, 2001; Abd-El-Khalick et al., 1998; Akerson & Abd-El-Khalick, 2003; Akerson et al., 2000; Bell et al., 2000; Lederman et al., 2001; Mellado, 1997). For most of these lessons, the preservice teachers used process skills-based nature of science instruction by first teaching a process skill and then linking the skill to a specific aspect of the nature of science. This was true even for new activities that the participants created. For example, when Monica showed a movie clip from “The Princess Bride,” she first had her pupils distinguish Prince Humperdink’s observations and inferences. Then she went on to illustrate through examples how scientists, like Prince Humperdink, use both observations and inferences to construct scientific knowledge.

During the exit interviews, all of the participants expressed the desire to include more nature of science instruction in the future when they have their own classes. Furthermore, most expressed dissatisfaction with the way that they had front-loaded the majority of their nature of science instruction during the early part of the school year. Despite these comments, not all of the participants’ nature of science instruction was relegated to the first few weeks of class. In fact, 11 out of 15 of the participants included nature of science lessons in the second half of the semester. It is encouraging to know that a previous cohort who experienced process skills-based instruction actually increased the quantity and quality of their nature of science lessons during their induction year of teaching (Bell et al., 2005).

In regard to pupil understandings about the nature of science, the results are mixed. On one hand, pre- to posttest gains on the modified VNOS-C were substantial. However, the overall scores for most of the participating classes were less than desired, and indicated that the pupils still had much to learn. Understanding key contextual factors should further clarify these results. The pupils were taught by beginning teachers who were coping with the complexities of classroom management, effective planning, and organizing content. In addition to these challenges, the preservice teachers were attempting to teach abstract concepts of the nature of science, which were relatively new to them. To further complicate matters, most of the nature of science instruction was concentrated at the beginning of the year, when the preservice teachers were teaching for the very first time and at their least effectiveness. Finally, it is important to note that the posttests were administered to pupils at the end of the semester, even though most of the nature of science instruction had occurred three months earlier. Consequently, the posttests were actually measuring long-term retention of nature of science understandings, which may have resulted in lower scores (as demonstrated for preservice elementary teachers in Akerson, et al., 2006). This is of special concern considering that many of the pupils’ alternative conceptions about the nature of science (i.e. the hierarchical relationship between theories and laws, that there exists a single scientific method, and the overall absolute view of scientific knowledge) had been developed over the course of many years and were tenacious. In this light, it is not surprising that pupils failed to achieve the desired conceptual change in such a short amount of time.

Previous interventions designed to promote nature of science instruction have not achieved the level of success described in the present study (Abd-El-Khalick, 2001; Abd-El-Khalick et al., 1998; Akerson & Abd-El-Khalick, 2003; Akerson et al., 2000; Bell et al., 2000; Lederman et al., 2001). In fact, difficulty getting teachers to address the nature of science instructionally has led some to conclude that "…all science teachers need NOS-specific support and professional development that goes beyond preservice education into in-service settings" (Akerson & Abd-El-Khalick, 2003). While there is no doubt that such support would be beneficial, it would prove costly and could never reach more than a small minority of teachers. Preservice teachers who experienced the intervention in the present study appear to have developed the desire and ability to teach the nature of science and to positively impact their pupils' understandings, without such high levels of support.

The final issue with our assessment of pupil achievement lies with the assessment tool itself. The VNOS is a validated instrument that has been effectively used in a number of investigations (Lederman et al., 2002). The open-ended nature of the VNOS-C combined with follow-up interviews provides researchers with a high degree of confidence that it is accurately measuring participants' understandings of the nature of science. Although it is a beneficial tool for research, the preservice teachers in this study found it less than desirable for classroom applications. For one thing, the VNOS-C is time consuming to administer. In fact, having completed the VNOS-C themselves, the preservice teachers in this study unanimously agreed that they could not afford the class time required to administer the full version as a pre- and posttest in their student teaching placements. Even the shortened version of the VNOS-C that the preservice teachers chose to use presented issues. For example, pupils answered many of the questions in a hasty or unclear manner, therefore reducing the validity of the assessment. Pupils working at lower achievement levels expressed frustration in understanding VNOS-C questions and articulating their own understandings. These factors emphasize the importance of the follow-up interviews. However, scheduling interviews with high school pupils during an already crowded day presents its own difficulties for classroom teachers. As more teachers incorporate nature of science instruction into their curricula, the need grows for classroom-friendly measures of pupil understandings of the nature of science.

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Appendix A

Views of the Nature of Science questionnaire form C (VNOS-C):

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?
2. What is an experiment?
3. Does the development of scientific knowledge **require** experiments?
   - If yes, explain why. Give an example to defend your position.
   - If no, explain why. Give an example to defend your position.
4. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?
   - If you believe that scientific theories do not change, explain why. Defend your answer with examples.
   - If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples.
5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.
6. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence **do you think** scientists used to determine what an atom looks like?
7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence **do you think** scientists used to determine what a species is?
8. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these **different conclusions** possible if scientists in both groups have access to and use the **same set of data** to derive their conclusions?

VNOS–Form C (continued)

9. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.
   - If you believe that science reflects social and cultural values, explain why. Defend your answer with examples.
   - If you believe that science is universal, explain why. Defend your answer with examples.
10. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
    - If yes, then at which stages of the investigations you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
    - If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

Appendix B

The Exit Interview Protocol included the following questions:

1. What do you think are the most important things to emphasize in your teaching? Why?
2. What in your opinion is the nature of science? What makes science different from other disciplines of inquiry (religion, philosophy, etc.)?
3. Do you think that teaching the nature of science is important? Why? (or Why not?)
4. Did you teach the nature of science? If yes, how? Why did you teach the nature of science in that particular way? (If not, why?) [Review with the student various relevant lesson plans where they included the nature of science.]
    a. If they taught the nature of science: What challenges did you face in the teaching of the nature of science?
    b. If they did not teach the nature of science: Did you consider teaching about the nature of science? (Why or Why not?)
5. What do you recall as having the biggest impact on your decision to teach/not teach about the nature of science? Among these four things, which had the greatest impact on your decision to teach the nature of science:
    a. Your high school experiences
    b. Your university science courses
    c. Your science education courses
    d. Your teacher mentors
6. Do you feel that you did enough to teach about the nature of science? Can you elaborate?
7. Do you feel your students learned the nature of science? What makes you say this? Did you assess your students' understanding of the nature of science? How did you do that: objectives, lesson plans, test items?
8. What, in your view, is the best way to teach the nature of science to your students?
9. How will you deal with the nature of science when you have your own class?
10. Do you remember writing anything in your reflective journals about the nature of science? Please tell me about this?

The follow-up interview protocol used in conjunction with the VNOS-C open-ended survey questionnaire included the following questions used by the interviewers as a guide (Related questions have been grouped together.):

1. What in your opinion is science?
2. How does science differ from other ways of knowing, such as philosophy or religion?
3. Why do theories change? (Or is new evidence/data the only reason theories ever change?)
4. What do you think comes first in scientific investigation, theory or observation?
    a. Why?
    b. Where did you learn these ideas?
5. Have scientists ever seen an atom?
    a. If so, how do they observe atoms?
    b. If not, how do they know what atoms know what atoms are like?
    c. Where did you learn these ideas?
6. Do scientific laws ever change?
    a. How would you rank scientific theories and laws in regard to importance?
    b. Can you give any examples of laws that have changed?
    c. Where did you learn these ideas?
7. What is the scientific method?
    a. Do all scientists use the scientific method when conducting investigations?
    b. Where does creativity fit in?
    c. Where did you learn these ideas?
8. How necessary are experiments in the development of scientific knowledge?
    a. Is any scientific knowledge developed without experiments?
    b. Where did you learn these ideas?
9. (Regarding responses of participants referring to instances when the participants believe a scientist's background influences the scientists' conclusions.) What do you mean by different backgrounds?
    a. How do these different backgrounds affect scientists' conclusions when they are looking at the same data?
    b. Is science simply a matter of interpretation? Is one person's view as good as the next?
    c. Is science subjective?
    d. Where did you learn these ideas?

Appendix C

The modified VNOS-C

1. Science textbooks often represent the atom as a central nucleus composed of protons and neutrons, with electrons orbiting the nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?
2. Is there a difference between a scientific theory and a scientific law? Explain your answer?
3. Scientists perform experiments/investigations when trying to solve problems. Do scientists use creativity and imagination when performing experiments/investigations? If you think not, explain why. If you think so, explain how they use creativity and imagination.
4. Scientists agree that about 65 million years ago the dinosaurs became extinct (all died away). However, scientists disagree about what had caused this to happen. Why do you think they disagree even though they have the same information?

Appendix D

The pupil interview protocol

Let's look at each question. Read what you wrote for an answer at the beginning of the semester, and read what you wrote at the end of the semester.

a. Did your answers change? How?
b. Would you still agree with what you wrote for your answer to the question at the end of the semester?

Ask student to elaborate on anything that is unclear.

a. For Q1, make sure they answer the second part to the question: what specific evidence do you think scientists used.
b. For Q2 have them restate the definitions of theory and law. Ask if one is more important than the other.
c. For Q3, ask them if they've heard of the scientific method and if they can state it. Ask if they think scientists always use this method when doing experiments or investigations.
d. For Q4, stress WHY scientists might disagree when they have all the same information.
e. Ask student if their overall views of science changed over the course of the semester. If so, ask them where they got their new ideas from.