# ACROSS CONTENT AND PEDAGOGY: SEEKING COHERENCE IN NOS INSTRUCTION IN TEACHER EDUCATION PROGRAMS

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Abstract

While reforms emphasize understanding the nature of science (NOS), a challenge in meeting the vision of the reforms is that teachers lack understandings consistent with contemporary views of NOS. Though teacher educators have successfully improved prospective teachers' views of NOS within science methods courses (Akerson et al., 2000) and specialized science content courses for teachers (Abd-El-Khalick, 2001; Hanuscin, et al., 2004), recent work questions whether such single-course efforts are sufficient to promote retention of improved views (Akerson, et al., 2006). From a conceptual change perspective, we examined the development of preservice elementary teachers' views of NOS across their program of study. Utilizing the VNOS-C (Lederman, et al., 2002), we conducted a pretest posttest for treated and comparison groups of both science content (physics) and pedagogy (methods) courses. 76% of participants who received NOS instruction in their science content course exhibited improved views, while only 14% of participants enrolled in a comparison section did so. Those who later enrolled in a methods course that emphasized NOS retained or further improved their views, while those who enrolled in a methods course in which NOS was not a primary focus reverted to their original views. Our findings underscore the importance of coherence in NOS instruction throughout teacher education.

## The Nature of Science in Science Education

The "nature of science" (NOS) typically refers to the epistemology of science or the values and assumptions inherent in the construction of scientific knowledge (Lederman, 1992). As Driver, Leach, Millar, and Scott (1996) emphasize, students need to understand NOS in order to be informed consumers of scientific information, make sense of socio-scientific issues, participate in decision-making processes, and appreciate science as a part of contemporary culture. While NOS has been emphasized as a critical component of scientific literacy within U.S. education reform documents including *Science for All Americans* (AAAS, 1990), *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996), a challenge in meeting the vision of these reforms is that teachers often lack understandings consistent with contemporary views of the nature of science (Abd-El-Khalick, Bell, & Lederman, 1998; Abd-El-Khalick & Lederman, 2000). Given the critical role teachers play in shaping students' conceptions of NOS, it is imperative to address this problem. Improving teachers' views of NOS is a first step towards the ultimate goal of enabling them to teach NOS effectively to their students.

Research indicates teacher educators have achieved some level of success in improving prospective teachers' views of NOS within science methods courses (Bianchini & Colburn, 2000; Gess-Newsome, 2002). In particular, instruction that is both explicit-and-reflective in nature has been shown to promote accurate views of NOS (Akerson, Abd-El-Khalick, & Lederman, 2000). Acknowledging that methods courses are only one part of prospective teachers' university preparation, however, other researchers have directed their attention toward improving views of NOS in science content courses. There is evidence specialized science content courses *for teachers* may serve as a fruitful context in which to address their views of NOS when similar explicit-and-reflective instruction is utilized to provide structured and guided opportunities for learners to examine and discern discrepancies between their NOS conceptions and those presented to them, clarify the presented NOS ideas and framework for themselves, and reflect on how specific aspects of NOS are illustrated by the curricular activities in which they participate through discussion and/or journaling (Abd-El-Khalick, 2001; Hanuscin, Phillipson-Mower, & Pareja, 2005).

While the above research seems to show promise, more recent work raises doubt whether such single-course efforts are sufficient to promote retention of improved views of NOS (Akerson, Morrison, & Roth-McDuffie, 2006). Though the preservice teachers in their study improved their views as a result of explicit instruction about NOS in a science methods course, many were found to have reverted back to their earlier (inaccurate) views five months later. This finding calls into question the purported "success" of previous single-course interventions described in the literature. Akerson et al. hypothesize that retention of improved views of NOS may be a developmental issue, but assert that a single-course intervention is simply not enough exposure to the nature of science to promote deep and lasting conceptual change.

While there is a proliferation of NOS research focusing on single-course interventions, few studies to date have examined the development of prospective teachers' NOS views over the long-term and across multiple course contexts. Indeed, within the present literature related to the nature of science, little is known about how teachers' views of NOS develop in the broader context of their university education. Our study seeks to address this gap in the literature, by examining the way in which preservice elementary teachers' views of NOS develop through both their content and pedagogical preparation. We adopted a view of learning as conceptual change, to explore the impact that instructional interventions undertaken in both a specialized physical science course for education majors and an elementary science methods course had on preservice teachers' understanding of NOS.

## Theoretical Framework

As Abd-El-Khalick and Akerson (2006) emphasize, conceptual change theory has guided many empirical studies of science teaching and learning and has been critiqued, extended, delimited, and revised by science educators since its emergence in the 1980s (Hewson, 1981; Posner, Strike, Hewson, & Gertzog, 1982). Solomon, Duveen, Scot, and McCarthy (1992) stated that explicit instruction and reflection about NOS, integrated within a conceptual-change approach, might better serve to enhance preservice elementary teachers' views of NOS. Similarly, Akerson, Abd-El-Khalick, and Lederman (2000) suggested that a conceptual change approach might be suited to promoting improved NOS views among preservice teachers by helping them become aware of their misconceptions and creating cognitive dissonance. Studies since (e.g., Abd-El-Khalick & Akerson, 2004) have utilized conceptual change as both a guide for teaching about the nature of science and a theoretical framework for identifying factors that mediate the development of preservice teachers' views of the nature of science. In their study of preservice elementary teachers, the researchers found this approach successful in promoting substantial and favorable changes in participants' views of NOS. Three factors were found to mediate development of views of NOS, including (1) internalizing the importance of NOS; (2)

interaction of NOS instruction with learners' global worldviews; and (3) a deep versus surface orientation to learning.

Consistent with the use of explicit-reflection instruction, a conceptual change approach to *teaching* about the nature of science makes NOS an explicit part of the classroom discourse, provides learners with structured opportunities to explain their ideas, discuss the strengths and limitations of those ideas, and assess the consistency of their ideas with those of others. Additionally, discourse is metacognitive, that is, "learners need to make their ideas and thinking an object of cognition" (Abd-El-Khalick & Akerson, 2004, p. 791). Using conceptual change as a theoretical framework for *researching* the effectiveness of interventions intended to promote improved views of NOS entails using the theory "to explicitly and functionally guide an intervention, design a study, collect and analyze data, and/or interpret findings" as well as using results to test and critically appraise the theory (Abd-El-Khalick & Akerson, 2006, p. 189). Discussions of conceptual change theory, its variants, and its criticisms can be found elsewhere (Abd-El-Khalick & Akerson, 2004; Clough, 2006; Duschl & Gitomer, 2006); rather than repeating those here, we highlight our use of this theory in the conceptualization and conduct of our research throughout the remainder of this manuscript.

## Methods

Given previous studies have emphasized "one course is not enough" (Akerson et al., 2006) to promote sustained conceptual change, we were interested in exploring the development of preservice elementary teachers' views of NOS over the course of their teacher education program, in their science content and science pedagogy courses. Additionally, we were interested in examining how NOS instruction in these two contexts supports conceptual change in views of NOS. We utilized a quasi-experimental design consisting of a pretest and posttest for treatment and comparison groups in both a content and science methods course (one followed by the other). Specifically, we sought to answer the following questions:

1. What differences in NOS views result from explicit versus implicit instruction about NOS in a science content course?
2. To what degree are changes in NOS views resulting from a one-course intervention retained?
3. What impact does receiving explicit NOS instruction in single versus multiple courses have on preservice teachers' views of NOS?

### *Context of the Study*

The Teacher Development Program (TDP) provides a program of study that leads to a Bachelor of Science in Elementary Education and leads to state certification to teach grades 1-6. Graduates of the program are prepared as generalists, who are responsible for teach all subject areas, including science. All Elementary Education majors are required to complete a minimum of 12 hours of coursework in the biological (5h), physical (4h), and mathematical sciences (3h), as well as a course in science pedagogy (3h). In this study, we were interested in how elementary teachers' preparation in science—across their content and pedagogical coursework—impacted their understandings of the nature of science.

The first course context of the study was *Exploring Principles of Physics*, a specialized content course for prospective elementary teachers offered by the Department of Physics. The course is intended to provide learners with a conceptual understanding of fundamental physics principles through hands-on and inquiry-based instruction. Students typically take this prerequisite course as freshmen or sophomores in Phase I of the TDP, though those who have taken high school physics may waive this requirement. The curriculum of the course focuses on four major units of study: electrical circuits, magnetism, force and motion, and light. Classes meet three days a week for a total of 4.5 hours. During class sessions, students work cooperatively in groups of three to complete a series of guided-inquiry exercises, each of which is followed by whole-class debriefing sessions focused on the underlying principles and concepts of the activities.

The second course context of the study was *Teaching Science in Elementary Schools,* a methods course offered by the College of Education. In Phase II of the TDP, all elementary education majors are required to enroll in this course. Classes meet for a total of 4.5 hours per week, during which time students participate in a variety of learning experiences intended to model specific pedagogical strategies such as cooperative learning, inquiry (in its various forms), and the learning cycle. While, much like the physics course, students are actively engaged in science experiences as learners, the focus of discussion following these activities focuses specifically on the pedagogical aspects of the experience and the role of the teacher in facilitating learning.

The first author, jointly appointed in the both the Department of Physics and Department of Learning, Teaching, and Curriculum in the College of Education, teaches one section of each course. Though observations of class sessions and examination of syllabi indicate the curricula and instruction in the other sections of each course were similar, NOS was a primary focus in only those sections taught by the first author (hereafter, treatment sections). Specific NOS interventions implemented in the treatment sections of each course are described below.

*Participants*

Participants in the study included 46 students (all female) enrolled in two sections of a physical science content course for prospective teachers at a large Midwestern university. One section included explicit-and-reflective instruction about NOS, while the other did not. 18 students (60%) in the treatment section agreed to participate, while 29 students (76%) in the comparison section opted to do so. In Phase II of the study, we followed 13 of the participants into their elementary science methods courses. The number of this participants in the second phase of the study is small, but can by explained by the following: 3 participants dropped out of the study; 8 participants changed majors and/or transferred universities; 9 participants were admitted to the Early Childhood Education program rather than the Elementary Education program and thus were required to take a different methods course; and 13 participants were not yet eligible for admission to their major, either due to insufficient GPA or not having completed prerequisite coursework. The number of participants in each course during each phase of the study is illustrated in Table 1.

**Table 1. Participants in the study.**

| **Phase I of the Study (n=46)** | | **Phase II of the Study (n=13)** | |
|---|---|---|---|
| | | Science Methods Course with NOS Instruction (treatment B) | Science Methods Course Without NOS Instruction (comparison B) |
| Physics Course with NOS Instruction (treatment A) | n=17 | n=2 | n=3 |
| Physics Course Without NOS Instruction (comparison A) | n=29 | n=3 | n=4 |

*Instructional Interventions*

Instruction in both treatment sections was designed to help students understand the same ideas about the nature of science that reforms advocate they teach their own students; specifically, that scientific knowledge (1) while durable, is also tentative and subject to change (2) is influenced by current theoretical frameworks and perspectives, as well as the perspective of the researcher (3) is based on and/or derived from observations of the natural world, or evidence (4) is a product of human creativity and imagination, (5) both influences and is influenced by the socio-cultural context in which it is generated, (6) produces both theories and laws, which have specific functions and relations to one another, and (7) is generated through a variety of methods, as opposed to a single, universal, and recipe-like method. Though there has been much debate regarding the exact characterization of the nature of science (see, for example, McComas, Clough, & Almazroa, 1998), researchers have found substantial overlap between the nature of science outlined in reforms and 'ideas about science' generated by an expert panel of 23 scientists, science educators, historians, sociologists, and philosophers of science through a Delphi study (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003), suggesting a growing consensus regarding aspects of NOS appropriate for inclusion in the curriculum.

Consistent with a conceptual change approach, explicit-and-reflective activities were utilized to provide structured and guided opportunities for learners to examine and discern discrepancies between their NOS conceptions and those presented to them, clarify the presented NOS ideas and framework for themselves, and reflect on how specific aspects of NOS are illustrated by the curricular activities in which they participate through discussion and journaling (Abd-El-Khalick, 2001). These included non-integrated or "content-generic activities" (Lederman & Abd-El-Khalick, 1998), as well as integrated or "content-embedded" activities (e.g., Khishfe & Lederman, 2006), described below and illustrated in Table 2.

**Table 2. Selected Examples of NOS Instruction Provided in Each Course**

| NOS Instruction | Exploring Principles of Physics | Teaching Science in Elementary Schools |
|---|---|---|
| Integrated/ content-embedded | History of Science – <br>• Discussion of conventional versus electron current and how notions have changed historically<br>• Examination of Mesmer's claims about "animal magnetism" and the testing of his claims to better understand experimental design<br><br>What does a law tell us? A theory?<br>• Discussion of Ohm's Law and Atomic Theory and comparison to theories and laws in terms of their level of generalization and scope | Utilizing children's literature to read about the work of scientists and meeting face-to-face with university researchers to discuss their scientific work<br><br>Reflecting on students' inquiry experiences in class and comparison to the work of scientists<br><br>Comparison/contrast of various types of scientific investigations (e.g., experiments, correlation studies, observational studies) |
| Non-integrated/ content-generic | Tricky Tracks (Lederman & Abd-El-Khalick, 1998)<br><br>Do you see a cow? (based on Lederman & Abd-El-Khalick, 1998) | The Great Fossil Find (Randak & Kimmel, 1999)<br><br>NOS Card Sort Activity (Cobern & Loving, 1998)<br><br>Umbrellaology (Smith & Scharmann, 1999) |

Content-generic activities were used to introduce students to each of the various aspects of NOS. These activities can be particularly useful for audiences with limited science content backgrounds, as they do not pertain to any specific content (Lederman & Abd-El-Khalick, 1998). Following each of the activities, whole-class discussions explicitly highlighted aspects of NOS and involved students in active discourse regarding the match and/or mismatch between their own ideas about science and those illustrated in the activity. Participants enrolled in comparison group sections of the courses did not engage in such content-generic NOS activities.

Unlike content-generic activities, *integrated* activities embedded NOS instruction within the teaching of the content of the course. Class discussions focused on relating aspects of NOS to both classroom laboratory activities and historical episodes about scientists' development of the concepts on which the activities focused. For example, to highlight the tentative nature of science, guiding questions were used to encourage students to reflect upon the epistemological dimensions of their own learning (e.g., How do you know? How certain are you? What evidence might change your ideas?) and to relate this to the nature of science as practiced by scientists (e.g., How did scientists determine this? Do you think they are absolutely certain? Why evidence might change their ideas?). Though students in the comparison section of each course participated in the same type of laboratory activities, they did not reflect upon nor discuss NOS explicitly in conjunction with those activities.

*Instruments*

We assessed participants' NOS views prior to, and upon completion of each course using the *Views of Nature of Science Questionnaire* (VNOS-C) (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Following recommendations by Lederman & O'Malley (1990), interviews were conducted to enhance validity. Because the first author was an instructor of the courses, the second author administered questionnaires and conducted interviews to protect the confidentiality of participants in the study.

*NOS Questionnaire.* We made several modifications to the VNOS-C (see Appendix A) based on our previous use of this instrument (Hanuscin, 2005; Hanuscin et al., 2005; Hanuscin, Akerson, & Phillipson-Mower, 2006) and interviews we conducted with participants regarding their written responses. We attempted to remain true to the intent of the questions included in the VNOS-C, and made revisions in order to improve the quality of responses we received. First, we modified the directions. We explicitly asked respondents to speculate and discuss their uncertainty about their ideas. In our prior work, we came across instances where respondents had simply written "I don't know". In interviews, we found that participants who had responded with "I don't know" were willing to offer conjectures, even if they were uncertain. We hoped the participants in this study might do the same if encouraged to do so on their written questionnaires. Keeping in mind that the nature of respondents' examples can be especially revealing and important in interpreting their responses (Hammer & Elby, 2003), we also added "Give an example." to the item 2 on the original VNOS-C ("What is an experiment?").

Second, we resequenced the items, shifting the original item 10 to the second position in the questionnaire, as we believe this item (which focuses on whether science is universal or socio-culturally embedded) provides further elaboration on respondents' definition of science (item 1). In our past research, we have found respondents are likely to reference conflicting interpretations about extinction (item 8) as an example of creativity in response to item 9, and thus we were concerned the sequence in which these questions were asked influenced participants' responses. Therefore, we moved the original item 8 to the end of the questionnaire, placing it *after* the item regarding scientists' differing interpretation of evidence regarding dinosaur extinction, rather than just before it.

Third, we revised several of the items to address difficulties participants had in interpreting the intent of the questions. In our past work, we found some respondents confused "development of scientific knowledge" (item 3) with developing knowledge as a *learner* in science classes, whereas the item is intended to elicit ideas about the enterprise of science. Thus, we reworded this item to ask "Do all scientists do experiments?" Additionally, for item 10 of the VNOS-C, we changed "science" to "scientific knowledge and practices." In our prior research, we found respondents focused on scientific *knowledge* being universal without commenting upon the *practice* of science (i.e., whether a universal "scientific method" exists).

We also revised several items to account for patterns of responses we identified in our previous studies. Minor changes were also made to items 4, 7, and 9 in order to shorten them and improve readability, while keeping to the purpose of the questions in eliciting ideas about particular aspects of NOS. Because we found open-ended questions provided us with more robust responses during interviews than we typically received through participants' questionnaires, we reworded several yes/no questions on the VNOS-C. For example, item 5 of the VNOS-C asks "Is there a difference between a theory and a law?" We revised the item to state "What is a scientific theory? What is a scientific law? How are they alike/different?" Similarly, rather than asking "After scientists develop a theory… does the theory ever change?" we revised the next item to state, "How do scientists develop theories and laws? Illustrate your answer with an example". In interviews, we found this to be a more fruitful question that would encompass the intended focus of this item on tentativeness of scientific knowledge.

*Interviews.* Given their reflective nature, interviews have a potential to serve as a treatment, and thus might confound results in a pre-post study of teachers' views. To enhance our ability to detect such effects, participants were randomly assigned to one of three groups: pre-interview, post-interview, and non-interview. Previous studies have indicated such a subset is "sufficient to gauge subtleties of meaning associated with a certain group of respondents or a certain context"(Lederman, et al., 2002). We conducted interviews using a semi-structured protocol adapted from Abd-El-Khalick and Lederman (2000). In the interviews, which lasted 20-45 minutes, participants were given a copy of their questionnaire responses and asked a series of follow-up questions intended to seek elaboration and clarification of their responses, as well as to identify coherence or inconsistency in their responses to different items (See Appendix A).

*Data Analysis*

Data from both questionnaires and interviews were entered into NVivo qualitative data analysis software. Alphanumeric labeling of each data source by a third party ensured blind analysis—neither researcher knew the identity of the participants or whether they were in the treatment or comparison groups of each course until necessary in the final rounds of the analysis. We employed a constant comparative method to ground our theory in the data (Glaser & Strauss, 1967). This approach consisted of:

- Comparison of individuals' interviews and questionnaire data
- Comparison within a single questionnaire (all data)
- Comparison of each participant's questionnaire data across all four administrations
- Comparison of questionnaire data within each groups (treatment/comparison I and II)
- Comparison across different groups of participants

In light of criticisms that "researchers often describe at great length how their studies were carried out, but remain vague when it comes to giving an account of the analysis" (Boeije, 2002, p. 392), we have attempted to make our process more transparent in the description that follows.

*Step 1.* At the start of our analysis, we compared transcripts of interviews and questionnaires for congruence. The aim of this comparison was to establish the validity of our questionnaire data. Important questions guiding our analysis included *What are the key views of NOS communicated in the questionnaire and interview? How do these align with one another?* And *Are there any expressions that are contradictory?* Upon finding a high degree of alignment between participants' interview and questionnaire responses, we proceeded under the assumption that the questionnaire data provided a valid assessment of participants' views of NOS.

*Step 2.* The next step in our analysis included a comparison of responses within each participant's questionnaire data from the first administration of the VNOS-C, at the beginning of the physics course. The aim of this comparison was to characterize each participant's stance in regard to the seven aforementioned aspects of NOS by examining responses across all ten items. Analytic memos made throughout this process enabled us to evaluate context-dependency of their NOS views, distinguish between levels of sophistication of views, and assess the nature of examples used to support their positions (Edmondson & Novak, 1993; Elby & Hammer, 2001; Hogan, 1999). Questions guiding our analysis at this stage included *Which codes are used to label responses to this particular response? What characteristics do responses with the same codes have in common?* We developed provisional categories to characterize epistemological perspectives for the different aspects of NOS, based on redundancy and intersection of codes, and generated a NOS profile for each of the participants (see Appendix B). This same process was repeated in subsequent rounds for post-data from the physics course, as well as pre and post-data from the science methods course. During these rounds, the coding schema was modified to reflect the emergence of novel responses, and new categories were developed to characterize epistemological stances not present in the previous data sets. Thus, a major result of this step in the comparison was refinement of the coding schema and development of profiles or typologies of NOS views of participants.

*Step 3.* The next step in the analysis involved comparing profiles of each participant's NOS views generated from analyses of the four administrations of the VNOS-C. The aim of this comparison was to identify changes in their conceptions of NOS following each course, as well as their retention of any changed views from one course to the next. Important questions to consider in this step of the analysis included *What are the similarities and differences between individual participants' profiles at each data collection point? Which responses represent a shift toward the views of NOS expressed in the reforms? Away from those?* In particular, we were concerned with inferring a conceptual change where none had occurred. This was addressed to some degree by conservative coding, in which codes assigned remained close to the data; however, we also made efforts to differentiate between a participant whose views were improved or enhanced and one who had made a fundamental shift in their epistemological stance.

*Step 4.* We next conducted a comparison of NOS profiles within groups of participants who were enrolled in the same sections of the two courses. The purpose of this comparison was to detect differences in patterns of change in views associated with our treatment, thus it was necessary to identify participants as belonging to either treatment or comparison groups. The main question guiding our analysis at this step included *What patterns of change are evident within each group? Is change more evident for some aspects of NOS versus others?* A summary of changes in NOS views for each group was generated through this analysis, enabling cross-group comparisons in the next step of the analysis.

*Step 5.* As a final step in the analysis, we compared patterns of change across various groups (e.g., interview/non-interview and treatment/comparison). In doing so, we were able to assess threats to internal validity, such as initial group differences in NOS views, as well as the effect of the interview as a treatment. Questions guiding our analysis at this stage included *How do the initial views of NOS compare across all groups? What patterns appear in one group but not in another and vice versa? Are there differences in patterns of change for individuals who were interviewed versus not interviewed?* This comparison allowed us to further associate changes in participants' views of NOS with the specific interventions utilized in the treatments sections of each course.

## Findings

To answer the first research question, we compared pre and post data from the first phase of the study, collected in the physical science content course. Participants in both sections of the course began the semester with similar views of the nature of science, which were largely inconsistent with those advanced by the reforms. No participant held views of any one aspect of NOS consistent with the reforms, though many did have views that were partially consistent with reforms. As described in previous studies (Abd-El-Khalick, 2001; Lederman, 1992), typical naïve views of science held by participants included viewing science as procedural versus creative, characterizing science as following a step-by-step "scientific method", and proposing that theories become laws when "proven". Table 3 illustrates the alignment of participants' views with the reforms at the onset of the study.

**Table 3. Alignment of Participants' Initial Views of NOS with the Reforms**

| Aspect of NOS | Partially Consistent with Reforms | Inconsistent with Reforms |
|---|---|---|
| Durability & Tentativeness | 35% | 59%† |
| Subjective/ Theory-laden | 61% | 39% |
| Inferential | 65% | 33%† |
| Empirical | 41% | 59% |
| Creative/Imaginative | 93% | 7% |
| Socio-cultural context | 63% | 33%† |
| Theories and Laws | 61% | 39% |
| Methods of Science | 19% | 78%† |

*†Percentages are not additive in cases where respondents provided too little information from which to draw inferences.*

Supporting examples provided by participants in response to the VNOS-C revealed their ideas (not surprisingly) were largely informed by "school science" experiences, versus their knowledge of science in the broader societal context. For example, in illustrating their definition of "experiment", respondents focused almost exclusively on school-based investigations, many of which included simple observations and activities, versus experimental designs in which there was an independent and dependent variable under investigation:

> For an example, I remember putting white flowers in an vase of water that had blue food coloring in it and we had to predict what would happen to the flower and if it would turn the color of the food coloring—if so, how long it would take to turn colors?
>
> I could do an experiment on whether or not red and blue make purple…

> Testing what happens to baking soda when vinegar is added.
>
> Example: Will a penny float in water; Hypothesis: If a penny is put in a cup of water then it will not float; Experiment: Put penny in cup of water; Results: My hypothesis was correct, a penny does not float in water.

Even those participants who could explicate features of experimental design focused on classroom-based investigations:

> Experiments have constant variables, an independent variable, and a dependent variable. They also have a method of collecting data. For example a scientist could study the effects of soil type on plant growth. Plants could be planted in diff types of soil & measured to see how tall they grow.
>
> An experiment is a test done to either support or refute a hypothesis. It must have an Independent and Dependent variable, and a control. Example – testing how long a plant lives by the type of fertilizer it is given.

Only eight participants provided examples of experiments from current scientific research. In each case, these were related to health and medicine:

> Ex: cloning (experiments are being done to secure a successful procedure).
>
> You can't just say that something is true w/out trying it first. For example, scientist can't just assume Cheerios are good for cholesterol, they would have to experiment w/different people.
>
> An experiment is a test of something. An example being finding a new prescription drug and a group of people willing to do a trial and documenting information gathered.

In contrast to examples used to illustrate experimental design, participants frequently provided examples in response to questions regarding the sociocultural embeddedness of science through citing socioscientific issues (whether or not their views were consistent with the reforms):

> I agree that science reflects the social and political values, because take cloning, we are unable to clone because of our beliefs and values.
>
> Scientist can work w/ others to figure things out and make new developments, example – space travel. Where political views might come to play is like nuclear war, American scientist might know how to do it, we just don't believe in using it.
>
> I think science is both. Different cultures may chose to explore different ideas. Political and social values guide what research is done and how it is done. Some people belief in animal testing others don't. Stem cell research as well. Overall science is universal though. The theories, laws, evidence, and discoveries found apply to all cultures.

Despite being asked to provide examples, relatively few – roughly 10% of respondents – were able to cite specific theories or laws in support of their ideas. Indeed, initial responses such as "salt melts ice" call attention to a lack of understanding of laws. Though several respondents did provide examples of specific theories and laws discussed in the physics course in subsequent administration of the VNOS (e.g., Ohm's law and atomic theory), their initial discussions of how theories and laws are developed revealed a general lack of understanding of these two forms of knowledge:

> Scientists develop theories and laws by research they have performed when studying a particular relationship or object. An example would be a theory scientists propose on why the sky is blue.

> It starts with an idea, then they experiment, then thousands of other scientist double check the idea-if no one proves it wrong it probably becomes a law or theory. For ex: When that guy discovered displacement and yelled "Eureka" everyone else probably checked his findings.

> They develop theories & laws by doing experiments or observations, & studying them. For instance, if a scientist was experimenting w/ acid rain & the affects on crops after a while based on evidence they could make a theory or if they prove it true, could make a law about how acid rain affects crops.

> Theories and laws are the result of scientists' ideas and observations. I think they come from and are closely linked to hypotheses and experiments. Perhaps a scientist notices that a certain lab rat takes a drink every hour on the hour. This particular scientist may decide to create a theory concerning the rat and may decide to create a theory concerning the rate and try to come to a conclusion based on experiments. From there, a law may or may not be formed.

At the end of the semester, changes in views of NOS were evident in responses of 13 (76%) participants who were enrolled in the treatment section, but only 4 (14%) participants who were enrolled in the comparison group section. Changes in views of NOS were no more evident in responses of those were interviewed versus those who were not, suggesting that the interviews did not serve as a treatment. Additionally, changes occurred more often in cases where participants' initial views were inconsistent with reforms, versus partially consistent with reforms. For example, changes were identified in 23 different cases in which participants' responses initially conflicted with the reforms; each of these was toward a view more consistent with the reforms. Whereas, only 6 changes were identified in cases in which participant's initial views were partially consistent with reforms. 2 of these included cases in which the change occurred toward a view consistent with the reforms, while 4 of these were toward a view inconsistent with the reforms.

All changes exhibited by the treatment group participants were towards views consistent with the reforms; however, not all changes observed in the comparison group were toward views consistent with the reforms. In the treatment group, the 17 participants each exhibited improved views for between 1 and 4 aspects of NOS including the tentative NOS, inferential NOS, creative NOS, socio-cultural context of science, function and relation of theory and law, and methods of science. In the comparison group, 3 participants acknowledged the lack of a single recipe-like method for generating scientific knowledge, while 1 shifted to a belief that science advanced through experiments alone. Additionally, 3 participants shifted to a view of science as universal. Changes in views of NOS for both treatment and comparison groups are illustrated in tables 4 and 5 below.

**Table 4. Changes in Views of NOS in the Treatment Group**

| Participant | Tentative | Subjective | Inferential | Empirical | Creative | Socio-Cultural | Theory/ Law | Methods of Science | Total Change |
|---|---|---|---|---|---|---|---|---|---|
| 38A | OØ | ⊗Ø | OØ | OØ | ⊗Ø | ⊗+ | OØ | OØ | **1** |
| 11A | OØ | OØ | OØ | OØ | O+ | O+ | O+ | O+ | **4** |
| 13B | ?Ø | OØ | ?Ø | OØ | ⊗Ø | ?Ø | OØ | OØ | **0** |
| 16B | ⊗Ø | ⊗Ø | OØ | ⊗Ø | ⊗Ø | OØ | O+ | ⊗Ø | **1** |
| 28B | OØ | OØ | O+ | ⊗Ø | ⊗Ø | ⊗Ø | O+ | ⊗Ø | **2** |
| 39N | ⊗Ø | ⊗Ø | ⊗Ø | OØ | ⊗Ø | ⊗Ø | O+ | OØ | **1** |
| 43N | ⊗+ | OØ | ⊗Ø | ⊗Ø | ⊗Ø | O+ | OØ | O+ | **3** |
| 6N | O+ | ⊗Ø | OØ | OØ | ⊗Ø | ⊗Ø | O+ | ⊗+ | **3** |
| 20A | OØ | OØ | OØ | ⊗Ø | ⊗Ø | O+ | OØ | O+ | **2** |
| 50A | ⊗Ø | OØ | OØ | ⊗Ø | ⊗Ø | ⊗Ø | O+ | OØ | **1** |
| 40B | OØ | ⊗Ø | OØ | OØ | ⊗Ø | OØ | OØ | OØ | **0** |
| 47A | OØ | ⊗Ø | OØ | ⊗Ø | ⊗Ø | ⊗Ø | O+ | OØ | **1** |
| 29A | OØ | ⊗Ø | OØ | OØ | ⊗Ø | ⊗Ø | O+ | O+ | **2** |
| 35A | OØ | ⊗Ø | OØ | OØ | ⊗Ø | OØ | OØ | OØ | **0** |
| 46B | OØ | ⊗Ø | OØ | ⊗Ø | ⊗Ø | ⊗Ø | OØ | OØ | **0** |
| 14N | ⊗Ø | ⊗Ø | OØ | ⊗Ø | ⊗Ø | ⊗Ø | O+ | OØ | **1** |
| 12N | OØ | ⊗Ø | OØ | ⊗Ø | ⊗Ø | ⊗Ø | O+ | OØ | **1** |
| **Totals** | **2** | **0** | **1** | **0** | **1** | **4** | **10** | **5** | **23** |

O denotes a view inconsistent with reforms
⊗ denotes a view partially consistent with reforms

Ø indicates no change in view
+ indicates a change toward consistency with reforms

**Table 5. Changes in Views of NOS in the Comparison Group**

| Participant | Tentative | Subjective | Inferential | Empirical | Creative | Socio-Cultural | Theory/ Law | Methods of Science | Total Change |
|---|---|---|---|---|---|---|---|---|---|
| 42N | ⊗Ø | ⊗Ø | OØ | ⊗Ø | ⊗Ø | ⊗Ø | OØ | O+ | **1** |
| 44A | ⊗Ø | ⊗Ø | OØ | ⊗Ø | ⊗Ø | ⊗Ø | OØ | ⊗Ø | **0** |
| 30N | ⊗Ø | OØ | ⊗Ø | OØ | ⊗Ø | OØ | ⊗Ø | OØ | **0** |
| 36N | ?Ø | ⊗Ø | OØ | ⊗Ø | ⊗Ø | ⊗Ø | OØ | OØ | **0** |
| 23A | ?Ø | ⊗Ø | OØ | OØ | ⊗Ø | ⊗- | OØ | O+ | **-1/+1** |
| 8A | OØ | ⊗Ø | OØ | OØ | ⊗Ø | ⊗- | OØ | OØ | **-1** |
| 7B | ⊗Ø | ⊗Ø | OØ | OØ | ⊗Ø | OØ | OØ | ⊗Ø | **0** |
| 25B | ⊗Ø | OØ | OØ | OØ | ⊗Ø | ⊗Ø | OØ | ⊗Ø | **0** |
| 37B | OØ | OØ | OØ | OØ | ⊗Ø | OØ | OØ | OØ | **0** |
| 5A | OØ | ⊗Ø | OØ | OØ | ⊗Ø | ⊗Ø | OØ | OØ | **0** |
| 15N | ⊗Ø | ⊗Ø | OØ | ⊗Ø | ⊗Ø | ?Ø | OØ | ⊗Ø | **0** |
| 18N | OØ | OØ | OØ | OØ | ⊗Ø | OØ | OØ | OØ | **0** |
| 21N | OØ | OØ | OØ | OØ | ⊗Ø | ⊗Ø | OØ | OØ | **0** |
| 1B | OØ | ⊗Ø | OØ | ⊗Ø | ⊗Ø | ⊗- | OØ | ⊗- | **-2** |
| 49B | OØ | OØ | OØ | OØ | ⊗Ø | OØ | OØ | OØ | **0** |
| 2A | OØ | ⊗Ø | OØ | OØ | ⊗Ø | ⊗Ø | OØ | ⊗Ø | **0** |
| 45N | OØ | OØ | OØ | ⊗Ø | ⊗Ø | OØ | OØ | OØ | **0** |
| 19B | OØ | ⊗Ø | OØ | OØ | ⊗Ø | ⊗Ø | OØ | OØ | **0** |
| 17A | OØ | ⊗Ø | OØ | OØ | ⊗Ø | ⊗Ø | OØ | OØ | **0** |
| 41A | OØ | ⊗Ø | OØ | OØ | ⊗Ø | ⊗Ø | OØ | OØ | **0** |
| 32A | OØ | OØ | OØ | OØ | ⊗Ø | OØ | OØ | OØ | **0** |
| 27N | OØ | OØ | OØ | ⊗Ø | ⊗Ø | OØ | OØ | OØ | **0** |
| 48N | ⊗Ø | ⊗Ø | OØ | ⊗Ø | ⊗Ø | ⊗Ø | OØ | O+ | **1** |
| 10B | OØ | ⊗Ø | OØ | OØ | ⊗Ø | ⊗Ø | OØ | OØ | **0** |
| 22B | ⊗Ø | OØ | OØ | ⊗Ø | ⊗Ø | ⊗Ø | OØ | OØ | **0** |
| 33N | ⊗Ø | OØ | OØ | ⊗Ø | OØ | ⊗Ø | OØ | OØ | **0** |
| 31B | ⊗Ø | ⊗Ø | OØ | OØ | ⊗Ø | ⊗Ø | OØ | OØ | **0** |
| 4B | OØ | ⊗Ø | OØ | OØ | ⊗Ø | OØ | OØ | OØ | **0** |
| 34B | ⊗Ø | OØ | OØ | OØ | OØ | ⊗Ø | OØ | ⊗Ø | **0** |
| **Totals** | **0** | **0** | **0** | **0** | **0** | **-3** | **0** | **-1/+3** | **-4/+3** |

O denotes a view inconsistent with reforms
⊗ denotes a view partially consistent with reforms
? denotes a lack of response/ no inference possible
Ø indicates no change in view
+ indicates a change toward consistency with reforms
- indicates a change toward inconsistency with reforms

Four months later, we followed 5 participants from the treatment section of the physics course into their science methods course. Two of these enrolled in the treatment section of methods, while three were enrolled in the comparison section. Those who enrolled in the treatment section of the methods course retained their improved views of NOS, and one exhibited additional favorable changes in her views. Of the three who enrolled in the comparison group of the methods course, one reverted back to her original views (inconsistent with the reforms), one exhibited no changes in her views of NOS in either the physics or methods course, and one retained a change in her views as well as reverted a previously changed view and improved another.

We also followed 7 participants from the comparison section of the physics course into their elementary science methods course. Of these, four enrolled in the comparison section of the methods course, in which NOS was not an explicit focus. None exhibited any improvements in their views of NOS, and one participant who had changed her views during the physics course reverted back to her original view, which was inconsistent with the reforms. Two of the three participants who enrolled in the treatment section of the methods course, in contrast, demonstrated favorable changes in their views of NOS. Table 6, below, highlights the views of each of these seven participants over the course of the study.

**Table 6. Longitudinal Profile of NOS Views of Participants in each Treatment & Comparison Section**

| Participant | Tentative | Subjective | Inferential | Empirical | Creative | Socio-Cultural | Theory/ Law | Methods of Science |
|---|---|---|---|---|---|---|---|---|
| **Treatment Group I & II** | | | | | | | | |
| 38A | O Ø Ø Ø | ⊗ Ø Ø Ø | O Ø Ø Ø | O Ø Ø Ø | ⊗ Ø Ø Ø | ⊗ + RR | O Ø Ø Ø | O Ø Ø + |
| 11A | O Ø Ø Ø | O Ø Ø Ø | O Ø Ø Ø | O Ø Ø Ø | O + RR | O + RR | O + - Ø | O + RR |
| **Treatment Group I Only** | | | | | | | | |
| 13B | ? Ø Ø Ø | O Ø Ø Ø | ? Ø Ø Ø | O Ø Ø Ø | ⊗ Ø Ø Ø | ? Ø Ø Ø | O Ø Ø Ø | O Ø Ø Ø |
| 16B | ⊗ Ø Ø Ø | ⊗ Ø Ø Ø | O Ø Ø Ø | ⊗ Ø Ø Ø | ⊗ Ø Ø Ø | O Ø Ø Ø | O + - - | ⊗ Ø Ø Ø |
| 28B | O Ø Ø + | O Ø Ø Ø | O + R R | ⊗ Ø Ø Ø | ⊗ Ø Ø Ø | ⊗ Ø Ø Ø | O + - - | ⊗ Ø Ø Ø |
| **Treatment Group II Only** | | | | | | | | |
| 42N | ⊗ Ø Ø Ø | ⊗ Ø Ø + | O Ø Ø Ø | ⊗ Ø Ø Ø | ⊗ Ø Ø + | ⊗ Ø Ø Ø | O Ø Ø Ø | O + - + |
| 44A | ⊗ Ø Ø Ø | ⊗ Ø Ø Ø | O Ø Ø Ø | ⊗ Ø Ø Ø | ⊗ Ø Ø Ø | ⊗ Ø Ø Ø | O Ø Ø Ø | ⊗ Ø Ø Ø |
| 30N | ⊗ Ø Ø Ø | O Ø Ø Ø | ⊗ Ø Ø Ø | O Ø Ø + | ⊗ Ø Ø + | O Ø Ø + | ⊗ Ø Ø Ø | O Ø Ø + |
| **Comparison Group I & II** | | | | | | | | |
| 36N | ? Ø Ø Ø | ⊗ Ø Ø Ø | O Ø Ø Ø | ⊗ Ø Ø Ø | ⊗ Ø Ø Ø | ⊗ Ø Ø Ø | O Ø Ø Ø | O Ø Ø Ø |
| 23A | ? Ø Ø Ø | ⊗ Ø Ø Ø | O Ø Ø Ø | O Ø Ø Ø | ⊗ Ø Ø Ø | ⊗ - + Ø | O Ø Ø Ø | O + - Ø |
| 8A | O Ø Ø Ø | ⊗ Ø Ø Ø | O Ø Ø Ø | O Ø Ø Ø | ⊗ Ø Ø Ø | ⊗ - Ø Ø | O Ø Ø Ø | O Ø Ø Ø |
| 7B | ⊗ Ø Ø Ø | ⊗ Ø Ø Ø | O Ø Ø Ø | O Ø Ø Ø | ⊗ Ø Ø Ø | O Ø Ø Ø | O Ø Ø Ø | ⊗ Ø Ø Ø |

O denotes a view inconsistent with the reforms
⊗ denotes a view partially consistent with the reforms
? indicates no response given/ no inference possible
Ø indicates no change in view
+ indicates a change in views toward consistency with reforms
- indicates a change in views toward inconsistency with reforms
R indicates a retained change in views

## Discussion and Implications

The findings of our study lend further support to the notion that specialized science content courses for teachers can be a fruitful context for teaching about the nature of science (Abd-El-Khalick, 2001). In addition, our use of comparison groups to examine the impact of the intervention strengthens the existing evidence for the effectiveness of explicit-and-reflective instruction undertaken within a conceptual change approach (Abd-El-Khalick & Akerson, 2004), and demonstrates that—even if the curricula are of an inquiry-based and hands-on nature—implicit attention to NOS by itself is not sufficient to challenge learners' epistemological beliefs about science (Abell, Martini, & George, 2001; Hanuscin et al., 2006).

In comparing participants' NOS views to the reforms, we noted that very few held views that were entirely consistent with the reforms, and chose to label these as "partially consistent" rather than "transitional" as has been done in previous studies. As Sandoval (2005) argues:

> …most students on most themes get coded as having transitional views, which means neither obviously naive nor clearly informed. It is not clear…why this position reflects a transition toward anything, as opposed to simply a mix of ideas (p. 644).

Consistent with our previous findings (Hanuscin et al., 2005), results from this study show that preservice teachers whose views of NOS were only partially consistent with the reforms (i.e., “transitional” in other studies) were no more likely to undergo conceptual change than those whose views were inconsistent with the reforms. Indeed, rather than changing their views, there is evidence participants inaccurately assimilated ideas about NOS presented in the course into their existing views. Thus, we did not consider these occurrences to be evidence of conceptual change.

Changes in views of NOS were not evident for all participants in the treatment sections, however, nor were they evident across all aspects of NOS. This finding may reflect a need for greater emphasis on NOS within the curriculum of these courses, and that interventions undertaken were not sufficient to produce cognitive dissonance. For example, though emphasis was given to each of the seven aspects of NOS espoused in the reforms, these did not receive equal attention within the curriculum of both courses. However, we did not identify a direct relationship between the amount of emphasis given to the various NOS aspects and the degree of change in views of participants.

An alternative explanation for this finding, then, is that participants’ views of NOS reflect more deeply-held epistemological beliefs that are resistant to change. Though our study spanned a period of a year, it is nonetheless only a brief window in participants’ science education. The ideas about NOS they brought to their teacher education program have been formed over years of school science experiences, experiences which typically do not reflect authentic science practices. As Sandoval emphasizes, “school science [is] so unlike professional science that we have no real hope to expect that students would develop robust epistemologies of science, or that we could study anything other than epistemologies of school science” (2005, p.646).

Clough (2006) applied Appleton’s (1997) constructivist model of learning in science to consider learners’ responses to the demands of conceptual change with specific regard to understandings of the nature of science. This model emphasizes that while learners would ideally exit from instruction only after their deep cognitive effort resulted in understandings that are both consistent with their learning experiences and congruent with accepted scientific knowledge, students may exit prematurely from instruction possessing what *appears* to be an idea that fits with their existing knowledge, but that does not conform to scientifically accepted views. When this occurs, Clough explains, “pre-existing NOS ideas have not been abandoned, only slightly modified or left intact with new schema created that are disconnected from the larger conceptual framework” (2006, p. 470).

The explanation above highlights the importance of considering learners’ broader schema and prior knowledge. For example, Abd-El-Khalick (2001) suggested that learning about specific NOS aspects might interact with learner’s broader epistemic views in ways that might hinder such learning. Similarly, Tsai (2002) found teachers’ beliefs about teaching, learning, and science are closely enmeshed, forming “nested epistemologies”. Thus, efforts to improve prospective teachers’ views of the nature of science might be confounded by their more naïve beliefs regarding teaching and learning, beliefs that have been formed over the entire course of students’ educational experiences. Though not specifically assessed in this study, the influence of such beliefs on preservice teachers’ learning to teach have been identified by a number of other researchers (cf., Kagan, 1992) and could likely have influenced their learning of NOS. Though we can draw no inferences about the differences in the development of participants’ NOS views in the context of a science content versus a science pedagogy course, given the attrition in our sample, others have suggested that instruction in NOS embedded in science teaching methods, rather than science content, impedes ability to translate learning into classroom practice (Abd-El-Khalick, 2001).

Our examination of participants' views of NOS was conducted utilizing the VNOS-C, an instrument widely used in assessing prospective teachers' views of NOS (Lederman et al., 2002). It should be noted, however, that the VNOS-C instrument study specifically targets respondents' ideas about the epistemology of science (i.e., as practiced by professional scientists), which Sandoval (2005) differentiates from "practical epistemologies" or learners' epistemological beliefs about scientific knowledge as constructed in the science classroom. The nature of the examples provided by our participants in response to the VNOS-C draws attention to their reliance on school science experiences as a basis for forming their beliefs about the scientific enterprise. Indeed these are indicative of relatively unsophisticated views of the nature of science, as illustrated in the case of preservice teachers' examples of experiments. With the exception of references to health and medical research, examples almost exclusively focused on school science activities, many of these drawn from participants' own K-12 experiences. This raises questions regarding the role that practical epistemologies play in the development of students' formal epistemologies, or beliefs about the enterprise of science, and how as researchers we can differentiate between and assess formal and practical epistemologies in meaningful ways (Sandoval, 2005). Additionally, as educators, our findings challenge us to consider the sufficiency of having students reflect on their own scientific practices if what is desired is a change in their views of the practice of professional science.

While we were only able to follow a limited number of participants from their content courses into the second phase of their teacher education program (science methods courses), our findings do provide evidence consistent with arguments advanced by Akerson et al. (2006) and call into question the purported success of previous efforts to improve teachers' views of NOS within a single semester. Participants from the initial treatment group who changed their views of NOS reverted back to their original views if they were enrolled in a methods course which did not emphasize NOS, but retained (and in some cases further improved) their views if they enrolled in a methods course which emphasized NOS explicitly. Though the inferences that can be drawn from such a small sample are limited, these findings are nonetheless encouraging, and warrant further investigation into the impact of NOS instruction in multiple course contexts (i.e., in both content and pedagogy courses). As Lederman, et al. emphasize:

> If we expect to develop high level understandings of complex knowledge such as NOS… systemic change is needed… throughout all aspects of subject specific teacher education programs so that NOS knowledge, subject matter knowledge, and PCK for NOS are uniformly and consistently addressed across all program components (2001, p. 157-8).

While elementary teachers are typically prepared as generalists, they nonetheless are also science teachers; thus the same notion applies. In particular, the proliferation of specialized content courses for elementary teachers lends itself toward promoting curricular coherency in their preparation. In our study, a faculty member jointly appointed in the sciences and education (first author) initiated these efforts. Similar initiatives might be undertaken via collaborative efforts of faculty from the sciences and education. However, our difficulty, as researchers, in tracking participants through two different course contexts alerts us to the difficulty we face, as teacher educators, in enacting such change and seeking coherence in terms of the way NOS is emphasized as an integral component of both science content and pedagogy coursework in teacher education programs. Thus, we caution that what Lederman et al. envision requires a programmatic commitment, and not just a collection of individual instructors working to improve their own courses.

Several distinct lines of research have emerged in regard to the nature of science in science education over past decades. According to Lederman (1992) these include a) assessment of student conceptions of NOS; b) development, use, and assessment of curricula designed to "improve" students' conceptions of NOS; (c) assessement of, and attempts, to improve teachers' conceptions of NOS; d) identification of the relationship among teachers' conceptions, classroom practice, and student conceptions. The first line of research helped identify the problem—that students in the U.S. were not “scientifically literate” in terms of their understanding of NOS. The subsequent lines of research have focused on situating that problem; first in attributing it to poor quality curriculum materials, next to poor quality teaching—due both to teachers’ own lack of understanding of NOS and their inability to translate NOS into practice and effectively teach NOS to their students. We initially located our work within the third line of research identified by Lederman, and indeed, situated our understanding of the problem within teachers and their views of NOS. We argue, however, that the findings of our study highlight a need to situate this problem not with *teachers*, but with *teacher education*.

Bransford, Darling-Hammond, and LePage summarize the research conducted over the past several decades in the field education and note:

> There is a great deal of variability in the information taught to teachers and the methods for doing so… as well as in graduates’ feelings of preparedness for different aspects of teaching (2005, p. 7).

It should not be surprising, given the variability in whether and how NOS is addressed throughout teacher education, that teacher candidates consistently fail to develop views of NOS aligned with the reforms. If, indeed, improving teachers’ views of NOS is a first step towards the ultimate goal of enabling them to teach NOS effectively to their students, we must develop a deeper understanding of the learning progression of NOS views and how that progression can best be supported through the broader context of teacher education programs. Only through building coherence in teacher education programs can we hope to address NOS in meaningful ways that provide teachers with the epistemic tools to both understand the nature of science and teach NOS effectively to their students.

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**Appendix A:**

Modified Views of Nature of Science Questionnaire
*(Interview probes appear in italics following each item.)*

Directions: Please respond to each of the following questions fully and completely. Keep in mind that we are interested in knowing *your* views of science; there are not "correct" answers to the items below. If you are unsure of your ideas, feel free to indicate so, and explain your uncertainty.

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)?

> *Tell me more about [your response]. Can you give an example of what you mean?*
> *What is meant when something is described as being "scientific"? Are there some things that aren't "scientific"? Explain.*

2. Some claim that scientific knowledge and practices are 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.

- With which, if either, claim do you agree? Provide examples to support your ideas.

> *Tell me more about [your response]. Can you give an example of what you mean?*
> *Do you think scientists can ever be entirely objective in their work? Why or why not?*

3. What is an experiment? Give an example.

> *Tell me more about [your response]. Can you give an example of what you mean?*
> **If "prove" used, ask How many experiments does it take to prove something? Can a scientific idea change once it's been proved?*
> **If "scientific method" referenced, ask What is the scientific method? Do all scientists follow this method? In all fields of science?*

10. Do all scientists do experiments?

- If yes, explain why. Give an example to defend your position.
- If no, explain why. Give an example to defend your position.

> *Tell me more about [your response]. Can you give an example of what you mean?*
> *What are the characteristics of a "good" experimental design?*
> *Do astronomers do experiments, such as you defined above? Would you consider conducting observations of the stars to be doing an experiment? Why or why not?*

5. What is a scientific theory? What is a scientific law? How are they alike/different?

> *Tell me more about [your response]. Can you give an example of what you mean?*

6. How do scientists develop theories and laws? Illustrate your answer with an example.

> *Tell me more about [your response]. Can you give an example of what you mean?*
> *After scientists develop a [theory or law] do these change? If so, how?*

7. 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 do you think scientists determined this? How certain are they that this is the structure of the atom?

  *Tell me more about [your response]. Can you give an example of what you mean?*
  *Have scientists ever seen an atom before? If so, what makes you believe that? If not, how are they still able to come up with its structure?*

8. 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 do you think scientists decided on this definition of species? How certain are they of this definition?

  *Tell me more about [your response]. Can you give an example of what you mean?*
  *Would you consider identifying a new species a scientific activity? How does this compare to your responses in item 3?*
  *Some species of dogs and wolves are known to interbreed and produce fertile offspring, yet wolves and dogs are considered different species. What do you make of this?*

9. It is believed that about 65 million years ago the dinosaurs became extinct. Several hypotheses have been proposed to explain extinction. 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. Another group of scientists suggests that massive and violent volcanic eruptions were responsible for the extinction.

- If both groups of scientists are using the same data, how do you think they came up with such different explanations?

  *Tell me more about [your response]. Can you give an example of what you mean?*
  *It is fair to say that the data are scarce; yet, scientists publish very pointed papers supporting these hypotheses. Why is that?*
  **If respondent indicates scientists would agree/know with more evidence, ask, "How much evidence would be needed to "know"? How much evidence would it take for all the scientists to agree?"*

10. Do creativity and imagination play a role in scientific investigations?

- If YES, do specify how scientists use their creativity and imagination. Give examples.
- If NO, tell why you think creativity and imagination are not involved. Give an example.

  *Tell me more about [your response]. Can you give an example of what you mean?*
  *How do you define creativity and imagination in terms of science?*

# Appendix B: Coding Schema for Comparing NOS Views with Reforms

| NOS Aspect | Consistent with Reforms | Partially Consistent with Reforms | Inconsistent with Reforms |
|---|---|---|---|
| Durability and tentativeness | Recognizes that while it is durable, *all* scientific knowledge is subject to change with new evidence or the reinterpretation of existing evidence. | Recognizes that scientific knowledge can change; however may indicate, for example, that scientific laws are "set in stone" and cannot change. | Views scientific knowledge as absolute, proven, and unchanging. |
| Subjective/ theory-laden | Recognizes that human subjectivity is inherent in all scientific work. Recognizes that current theories serve as a lens through which we view data, and guides future work. | Understands that subjectivity can play a role in the development of scientific knowledge; however this viewed as bias/ unethical conduct by scientists. | Views science/scientists as objective and value-free. Differing interpretations occur because it can't be determined which is "right." |
| Inferential | Recognizes that it is not possible to directly observe all phenomena; however, through indirect evidence it is possible to make logical inferences about these phenomena. | Recognizes use of both observation and inference in science; however, may still focus on an ultimate need for direct observation as evidence. | Ascribes to the notion that "seeing is believing" and fails to recognize the role of indirect evidence in science. |
| Empirical | Recognizes scientific claims must be based on empirical evidence (whether direct or indirect) and that they are limited to natural phenomena. | Refers to "data" and "testing," however, may not recognize this as distinguishing science from other disciplines of inquiry (e.g., religion). May focus on science as a democracy/ role of consensus. | Fails to recognize reliance on evidence to support scientific claims. May emphasize individual beliefs and opinions over evidence. |
| Creativity & imagination | Considers creativity/imagination a vital part of all stages of scientific investigations (not only planning/interpretation). Recognize that ideas (theories, hypotheses) are created. | Recognizes role of creativity and imagination in scientific investigation; however, may indicate that some aspects do not/ should not involve creativity/imagination (ex: data collection) | Views science as procedural, rather than creative. |
| Socio-cultural context | Recognizes that science, as a human endeavor, both influences and is influenced by society and culture. May view science as a culture unto itself. | Recognizes either the influence of society/ culture on science or vice versa (but not both). May emphasize science as "universal" in ontological terms, as in describing a single reality. | Views science as universal and/or separate from society/culture. |
| Theories and laws | Recognizes theories and laws as end product of science, and distinct from one another. Understands that laws are primarily descriptive of relationships between variables and that theories may explain or encompass laws. | Recognizes that theories and laws are fundamentally different (theories do not become laws) however, unable to articulate clear definitions, provide examples, etc. | Holds a hierarchal view of the function and relation of theory and law, in which theories (untested speculations) become laws (proven facts). |
| Use of multiple methods of investigating | Scientists use a variety of methods including experiments, observations, and collecting specimens. There is no single, universal, recipe-like "scientific method" that captures this diversity of methods. | May confuse "experiment" with ANY form of scientific investigation.<br><br>May view experimental designs are superior to other designs (e.g., observational studies) | Believes there is one, universal "scientific method" followed by all scientists in all field. Fails to recognize methods other than experimental designs (involving control and manipulation of variables). |