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ABSTRACT

This study assesses the influence of a philosophy of science course a preservice secondary science teachers' view of the nature of science; perceptions of teaching about the nature of science in future classrooms; and instructional planning related to the nature of science. It was exploratory and interpretive in nature. Data collection was continuous and spanned the duration of the study. The participants were preservice secondary science teachers (n=32) enrolled in the first 2 semesters of a 2-year combined undergraduate-graduate teacher preparation program. This study indicates that the investigated philosophy of science course resulted in deeper understandings of the nature of science on the part of the participants. It also indicates that more concerted and extended efforts that go beyond a few hours of nature of science-related instruction in a science methods course should be undertaken if the desire is to address the instruction of science teachers in the nature of science. (Contains 69 references.) (MVL)

The Influence of a Philosophy of Science Course on Preservice Secondary Science Teachers' Views of Nature of Science

by
Fouad Abd-El-Khalick

THE INFLUENCE OF A PHILOSOPHY OF SCIENCE COURSE ON PRESERVICE SECONDARY SCIENCE TEACHERS' VIEWS OF NATURE OF SCIENCE

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Introduction

During the past 85 years, almost all scientists, science educators, and science education organizations have agreed on the objective of helping students develop informed views of nature of science (NOS) (Abd-El-Khalick, Bell, & Lederman, 1998). Presently, despite their varying pedagogical or curricular emphases, agreement among the major reform efforts in science education (e.g., American Association for the Advancement of Science [AAAS], 1990; National Research Council [NRC], 1996) centers around the goal of enhancing students' views of NOS.

However, research has consistently shown that K-12 students have not attained the desired understandings of NOS (Duschl, 1990; Lederman, 1992). Similarly, science teachers were found to harbor several naïve views of NOS (e.g., Abd-El-Khalick et al., 1998; Billeh, & Hasan, 1975; Bloom, 1989; King, 1991). To mitigate this state of affairs, several attempts were undertaken to improve science teachers' NOS views (e.g., Akindehin, 1988; Billeh, & Hasan, 1975; Haukoos & Penick, 1983, 1985; Ogunniyi, 1983; Olstad, 1969). In a comprehensive review of these attempts, Abd-El-Khalick and Lederman (2000) concluded that these efforts were generally not successful in helping teachers develop understandings that would enable them to effectively teach about NOS. Nonetheless, they noted that an explicit reflective approach to enhancing teachers' conceptions (e.g., Abd-El-Khalick et al., 1998; Dickinson, Abd-El-Khalick, & Lederman, 1999; Shapiro, 1996) was relatively more effective than an implicit approach that utilized hands-on or inquiry science activities lacking explicit references to NOS (e.g., Barufaldi, Bethel, & Lamb, 1977; Haukoos & Penick, 1983, 1985; Riley, 1979).

Yet, in our own research, we found that even though an explicit reflective approach undertaken within science methods courses was successful in positively influencing science teachers' views of NOS, the translation of these views into instructional practices was, at best, limited and mediated by several variables (Bell, Lederman, & Abd-El-Khalick, 2000; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001). Among these factors was science teachers' *depth* of understanding of the target NOS aspects. Abd-El-Khalick and Lederman (2000) argued that to be able to effectively teach about NOS, science teachers need to have more than a basic knowledge and understanding of some NOS aspects. Teachers need to know a range of related examples, demonstrations, and historical episodes. They should be able to comfortably discourse about these NOS aspects, contextualize their NOS teaching with some examples or "stories" from history of science, and design science-based activities to render the target NOS aspects accessible and understandable to K-12 students. In other words, science teachers need to have some level of NOS pedagogical content knowledge (NOS PCK).

There is a limit to what can be done within the context of science teacher education programs given their already extensive and overly long agendas. Thus, the efforts undertaken within these programs to help prospective teachers develop deep understandings of NOS need to be augmented with relevant coursework in other disciplinary departments. Intuitively, coursework in philosophy and history of science serve as primary candidates. Indeed, during the past 40 years, science educators have repeatedly argued that philosophy of science (POS) can play a significant role in helping learners develop more informed conceptions of NOS (see Matthews, 1994; O'Brien & Korth, 1991; Robinson, 1969; Scheffler, 1973). However, despite the longevity of these arguments, and to the best of the researcher's knowledge, there are no systematic empirical studies in the science education literature that examined the influence of

POS courses on science teachers' NOS views or related instructional practices.

NOS

Philosophers, historians, and sociologists of science, and science educators are quick to disagree on a specific definition for NOS. The use of the phrase "NOS" throughout this proposal instead of the more stylistically appropriate "the NOS," is intended to reflect the author's lack of belief in the existence of a singular NOS or general agreement on what the phrase specifically means. This lack of agreement should not be disconcerting or surprising given the multifaceted, complex, and dynamic nature of the scientific enterprise. It is our view, nonetheless, that there is an acceptable level of generality regarding NOS that is accessible to K-12 students and at which virtually no disagreement exists among experts (Lederman & Abd-El-Khalick, 1998).

Some of the aspects of NOS that fall under this level of generality are that scientific knowledge is: tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), theory-laden, partly the product of human inference, imagination, and creativity (involves the invention of explanations), and socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences, and the functions of, and relationship between scientific theories and laws. These NOS aspects, which were adopted and emphasized in this study, have been emphasized in recent science education reform documents (e.g., AAAS, 1990; NRC, 1996).

Method

The present study was exploratory and interpretive in nature. The study aimed to assess the influence of a POS course on preservice secondary science teachers' (a) views of NOS, (b) perceptions of teaching about NOS in their future classrooms, and (c) instructional planning related to NOS. Data collection was continuous and spanned the duration of the study. Numerous data sources were used to answer the questions of interest. Figure 1 presents an overview of the study's participant students and courses, timeline, procedure, instruments, and data sources.

Participants

Participants were all 32 preservice secondary science teachers, 20 female (62%) and 12 male (38%), enrolled in the first two of a four-semester science methods course sequence. This course sequence is a part of a two-year combined undergraduate-graduate teacher preparation program at a large Midwestern University. Participants' ages ranged from 19 to 25 years (M = 20.9 years, SD = 1.3 years). Of the participants 3 (9%) were juniors, 20 (62%) were seniors, and 9 (28%) were graduates. With one exception, all graduate students had just started their graduate studies and, thus, were not substantially different in their ages and science content backgrounds from the greater majority of the undergraduate participants.

The study spanned two semesters. During Fall term, all participants were enrolled in the first science methods course (Science Methods I). During Spring term, all participants were enrolled in the second science methods course (Science Methods II). Additionally, four of the graduate participants, three female and one male (M = 22 years) were enrolled in a graduate survey course of POS (see Figure 1).

Context and Intervention

The intervention was undertaken in the context of the aforementioned three courses, which are taught by the author. Science Methods I aims to introduce students to teaching science in a diverse society. The course explores the goals for science education past and present, contemporary conceptions of NOS, the diversity of secondary school students, "science literacy for all" in the context of a diverse society, and current directions and trends in science education. Over the course of 12 instructional hours toward the beginning of this course, a set of 15 generic activities and three readings were used to provide participants with opportunities to examine and reflect on their own views of NOS, and to explicitly introduce them to the target aspects of NOS. Detailed descriptions of these activities can be found elsewhere (Lederman & Abd-El-Khalick, 1998). A whole-class discussion followed each activity and involved students in active discourse concerning the presented NOS aspects.

Additionally, in Science Methods I, participants wrote two NOS-specific reflection papers in response to two readings. The first paper, which was written toward the beginning of the explicit reflective NOS instruction sessions (see Figure 1), was in reaction to the McComas (1996) reading. Students were asked to discuss the NOS ideas presented in the reading and compare those ideas with their own NOS views. This paper was intended to get participants' to clarify and confront their own views of NOS. For the second reflection paper, participants were asked to read the prologue for Penrose's (1994) *Shadows of the Mind: A Search for the Missing Science of Consciousness*, and answer the following questions: "Do the ideas in this reading fit our discussions of some aspects of NOS? If yes, how? If no, why?" This short reading is a dialogue between young Jessica and her father. The father, a scientist, goes into a cave to collect some plant specimens and Jessica goes along. While inside, Jessica wonders what would happen if she, her father, and others got trapped inside the cave. Eventually, Jessica comes to ask, "How could I know what the real world outside was like? Could I know that there are trees in it, and birds, and rabbits and other things?" (Penrose, 1994, p. 2). The ensuing conversation focuses on how we “know” and how “valid” our knowledge is, as Jessica’s father tries to explain to her how much they could learn about the outside world just by observing whatever shadows that might form on their cave walls. This second reaction paper was written following the conclusion of NOS instruction and was meant to provide students with an opportunity to reflect on their newly acquired NOS understandings (if any) and apply them in a novel context.

Science Methods II engages participants in a set of extended inquiry activities and other science teaching modalities for the purpose of providing them with learning experiences that are commensurate with ones that these preservice teachers are expected to foster in their own future classrooms. Activities are followed with structured discussions aimed at getting participants to reflect on the sort of learning experiences they have engaged, how these experiences differ from the traditional science teaching that many of these participants have experienced in their own science learning careers, and articulate the benefits and burdens of these espoused teaching approaches. The course also aims to help prospective teachers acquire practical skills in (a) planning science lessons that are consistent with current trends in science education, (b) utilizing a variety of media and resources for teaching.science, and (c) applying various approaches to teaching science in secondary classrooms. In this course, participants prepared four detailed lesson plans that utilized a variety of instructional approaches, but that addressed topics and objectives of the students own choosing. Participants used their fourth lesson plan to guide their 30-minute peer teaching lessons toward the conclusion of the course. Following the completion of the fourth lesson plan, students wrote a reflection paper in which they discussed the impact that the discussed ideas about NOS in the two methods courses might have on their future teaching practices.

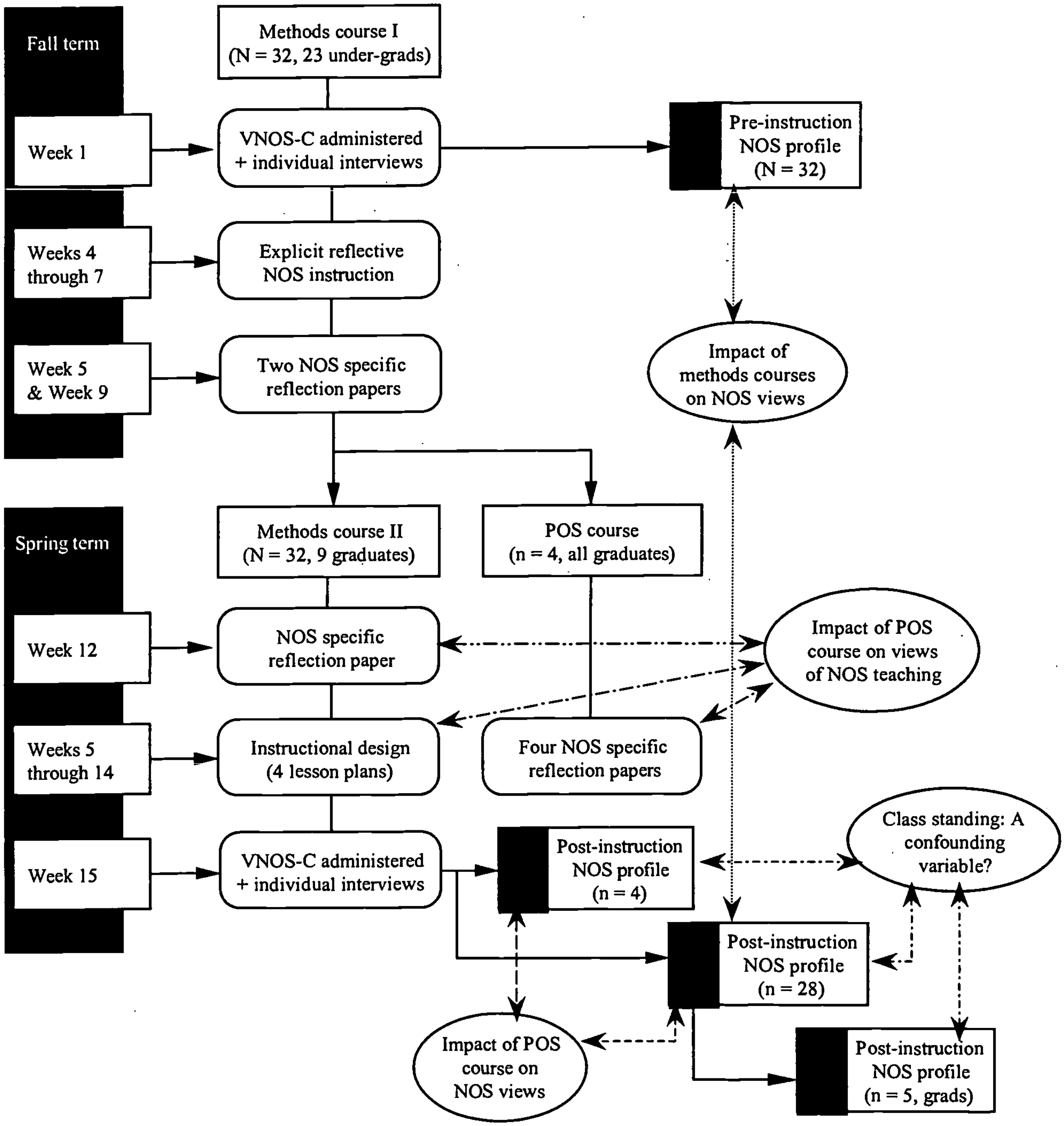

Figure 1. An overview of the study's participant students and courses, timeline, instruments, and data sources.

The POS course surveys issues that are central to science education through an exploration of the original works of twentieth century philosophers of science who were most influential in shaping thinking about science in the science education community. Relevant readings from science and history of science are also explored. Table 1 presents an overview of the topics addressed in the course along with some illustrative readings. The course aims to help students develop informed and critical views of NOS and its implications for science teaching and learning. To help students achieve these latter goals, they were required to write a total of four extended reflection papers in which they discussed the major ideas discussed in a set of sessions, compared these ideas about science with their own views, assessed any changes in their own NOS views, and discussed the ways in which, if any, the presented ideas were related to teaching pre-college science.

The experiences detailed above were the only explicit encounters that participants had with NOS during Fall and Spring terms. Participants were not enrolled in any other directly relevant courses (e.g., history, philosophy, or sociology of science courses). So, for the purpose of this study, participants could be situated in two groups: The "Methods" group, which comprised participants enrolled in the two methods courses, and the "POS" group, which comprised participants enrolled in the methods and POS courses. This grouping allowed assessing the impact of the POS course on participants' NOS views and perceptions of teaching about NOS (see Figure 1).

Procedure

The *Views of Nature of Science Questionnaire–Form C* (VNOS–C) (Abd-El-Khalick, Lederman, Bell, & Schwartz, 2001) was used to assess participants' views of the target NOS

Table 1

Overview of the Topics Addressed in the POS Course

Topic(s)	Illustrative readings
Induction and its failings, Bayesianism, Popper's falsificationism and its failings	Selections from Russell (1959), Harre' (1983), O'Hear (1989), and Popper (1992)
The Duhem-Quine thesis and underdetermination	Duhem (1998), Quine (1998) Case study: The dinosaur extinction controversy (Alvarez & Azaro, 1990; Courtillot, 1990; Glen, 1990, 1994)
Observation, theory, and incommensurability Kuhn on normal science, revolutions, resolutions, and progress	Kuhn (1996, 1998) Case study: The Copernican revolution (Kuhn, 1985)
Kuhn and his critics	Feyerabend (1993), Popper (1993), Watkins (1993) Case study: N-rays (Nye, 1980)
Sophisticated falsificationism	Lakatos (1993)
Empiricism and realism	Maxwell (1998), Toulmin (1998), Musgrave (1998), van Fraassen (1998) Case study: Competition in community ecology (Lewin, 1983; Roughgarden, 1983; Simberloff, 1983; Sloep, 1993)
Science and Pseudoscience	Feyerabend (1998), Lakatos (1998), Laudan (1998), Popper (1998), Ruse (1998a, b), Thagard (1998)
Science as social knowledge	Selection from Bloor (1976) and Longino (1990) Case studies: Selections for Collins and Pinch (1993)
Feminist approaches to science	Giere (1998), Keller (1997) Case study: Hominid evolution (Haraway, 1978, Hrdy, 1986; Lovejoy, 1981)

aspects at the beginning of Fall term and end of Spring term. Given the study's concern with the meanings that participants ascribed to the emphasized NOS aspects, it was imperative to avoid misinterpreting participants' responses to the *VNOS–C*. As such, individual semi-structured interviews were used to establish the validity of the questionnaire by insuring that the researcher's interpretations of participants' written responses were congruent with those elucidated by participants during the interviews. Eight randomly selected participants (25%) were interviewed: Four following the first administration of the *VNOS –C* and four following the second administration of the instrument. This latter procedure was undertaken to avoid the introduction of the pre-instruction interview, which could have served as a treatment, as a confounding variable that could influence participants' responses during post-instruction interviews. This approach allowed the use of post-instruction interview data both to establish the validity of the questionnaire and facilitate the interpretation of changes in participants' views.

During the interviews, which were conducted by the author, participants were provided with their pre- or post-instruction questionnaires and asked to explain and justify their responses. Follow-up questions were used to clarify participants' responses and further probe their lines of thinking. All interviews, which typically lasted about 45 minutes, were audio-taped and transcribed for analysis.

Additionally, participants' NOS-specific reflection papers from all three courses, and their lesson plans from the Spring science methods course were collated for analysis. The reader is reminded that while the reaction papers included explicit cues for participants to discuss issues related to the nature of the scientific endeavor and teaching about NOS, participants were not given any cues whatsoever for choosing topics or objectives for their lesson plans.

Data Analysis

The author analyzed the data. Another science educator conducted a blind round of analysis. The two analyses were compared and differences were resolved by consensus. This procedure was undertaken to insure the validity of the analysis given that the author was the instructor of the participant courses and could have perceived the data as partially evaluative.

Data analysis featured three phases. During the first phase, the collected lesson plans were searched for evidence to assess whether the participants planned to teach about NOS. The analysis focused on documenting explicit planned instances, including instructional objectives that were coupled with activities and/or discussions that overtly addressed one or more of the target NOS aspects. Isolated statements or references related to NOS that were inserted into an instructional sequence or glossed over during a planned discussion were not considered explicit instances of planning to teach about NOS. Moreover, activities that were consistent with a particular view of science, but did not explicitly focus students' attention on a target NOS aspect were also not considered explicit planned instances. For example, students' performance of a laboratory investigation was not considered an explicit instance of teaching about NOS, unless participants included planned questions aimed at engaging their students in a relevant discussion that emphasized certain NOS aspects.

During the second phase of data analysis, participants' NOS-specific reflection papers were examined to gauge changes in participants' NOS views and assess their views regarding teaching about NOS in their future classrooms. The reader is reminded that the Methods group participants addressed this question in a reflection paper written toward the end of the Science Methods II course, while the POS group grappled with the same question throughout the POS course (see Figure 1).

Participants' *VNOS–C* questionnaire responses were examined during the third phase of data analysis. Analysis started with the pre-instruction questionnaires of the four randomly interviewed participants, which were used to generate a profile of their NOS views. The corresponding interview transcripts were then used to generate another profile of these participants' views. The independently generated profiles were compared and indicated that the researcher's interpretations of participants' NOS views as elucidated in the *VNOS–C* were congruent to those expressed by participants during individual interviews. This procedure was repeated with the post-instruction questionnaires and interview transcripts of the other four interviewees resulting in similar congruency. Next, all questionnaires were analyzed to generate pre- and post-instruction profiles of participants' views. Each questionnaire was used to generate a summary of a participant's NOS views. These summaries were then searched for patterns or categories, which were checked against confirmatory or otherwise contradictory evidence in the data and were modified accordingly. Several rounds of category generation, confirmation, and modification were conducted to satisfactorily reduce and organize the data for a certain group of participants.

It should be noted that a decision was made to analyze participants' lesson plans prior to examining their NOS-specific reflection papers and *VNOS–C* questionnaires in order to avoid biasing the results of analyzing these instructional plans. Examining participants' NOS views and their statements regarding teaching about NOS in their future classrooms prior to analyzing their lesson plans could have created a mindset that might have lead the researchers to read into some participants' instructional plans and inaccurately categorize some planned sequences as explicit instances of planning to teach about NOS. As such, examining participants' reflection papers and *VNOS–C* questionnaires was deferred to the latter phases of the analysis.

To answer the questions that guided the present investigation, the results of each of the above analyses (i.e., lesson plans, refection papers, and *VNOS–C* questionnaires) were clustered by group of interest (i.e., the Methods group *versus* the POS group). Next, the group results were compared and contrasted to assess the impact of the POS course on participants' NOS views, perceptions of teaching about NOS in their future classrooms, and instructional planning related to NOS. Finally, it should be noted that the four participants in the POS group (i.e., students enrolled in the Methods and POS courses) were graduate students, while the greater majority of the Methods group participants (i.e., students enrolled in the Methods courses only) were undergraduates. To assess the possibility of class standing (graduate *versus* undergraduate) being a confounding variable in the present study, the aforementioned results were also clustered for the five graduate students in the Methods group and compared with the results for students in the POS group (see Figure 1).

Results

In the following sections, the letters "M" and "P" followed by a numeric are used to refer to individual participants in the Methods and POS groups respectively. Moreover, it should be noted that comparisons between the Methods group participants less the graduate students, the graduate students enrolled in the methods courses only, and the POS group allowed ruling class standing (i.e., undergraduate vs. graduate) as a confounding variable in the present study. The NOS views, views of teaching about NOS, and instructional planning related to NOS of graduate students in the Methods group were not systematically or substantially different from those of the undergraduate students.

Participants' Views of NOS

The NOS views of participants in the Methods and POS groups did not differ in any respect at the outset of the study. A majority of participants held naïve views of several of the target NOS aspects. Table 2 presents a summary of the pre-instruction NOS views of the Methods group participants, which is illustrative of the views of all participants. This summary appears in the second and third columns of Table 2. It should be noted that while column 2 reports the percentage of participants with informed views of the specified NOS aspect, column 3 presents an illustrative quote of participants' naïve views of this aspect.

Consistent with prior research findings (see Abd-El-Khalick & Lederman, 2000), a large majority of participant preservice teachers (90%) ascribed to a hierarchical view of the relationship between scientific theories and laws whereby theories become laws when "proven true." Also, as evident in Table 2 (columns 2 and 3), an alarming majority of participants (75%) seemed to believe that scientific knowledge is not tentative. Some of these participants articulated this view explicitly, while others conveyed it in their responses to various *VNOS–C* items. For instance, while almost all participants indicated that scientific theories do change with the advent of new evidence and the development of better technologies, a large majority believed that scientific laws are "facts" and not amenable to change because they are "proven to be correct." This latter view coupled with participants' belief in a hierarchical relationship between theories and laws, indicates that their comments regarding theory change were not associated with a tentative view of science. Rather, these comments reflected a naïve view of scientific theories as an intermediate step in the generation of "true" scientific knowledge (i.e., laws and facts). Indeed, about 70% of participants did not demonstrate informed views of the well-substantiated nature of scientific theories, their explanatory and predictive functions, and their crucial role as frameworks for guiding research. Instead, many participants ascribed to the term "scientific theory" meanings associated with the vernacular sense of the word theory as "someone's guess of what is going on."

Similarly, only about 30% of participants articulated informed views of the inferential, and creative and imaginative NOS. For instance, many participants noted that scientists were "certain" about atomic structure because "high powered microscopes" were used to discern this structure. Scientific models or representations of the atom were, as such, thought of as depictions of the way an atom "really" is. Participants failed to distinguish between scientific claims and the evidence supporting such claims. This conflation, according to which 'knowing is seeing,' transferred into participants' (uninformed) discussions of theories whereby many indicated that scientific theories could not be tested because, for instance, "no one was around when the dinosaurs became extinct . . . so, we will never know which extinction theory is true" (M12). Additionally, even though many participants noted that scientists use creativity and imagination in their work, only a handful (28.6%) articulated the view that such human attributes are integral to the creation of scientific models, theories, and explanations. Participants mostly used the term "creativity in science" to refer to scientists' resourcefulness in designing experiments and collecting data or their ability to make science interesting and accessible to the public.

A small minority of participants (17.9%) seemed to appreciate the theory-laden nature of observations and investigations. For instance, the majority dismissed the dinosaur extinction controversy on the scarcity of the evidence, with the implication that "when enough data is found, one hypothesis will become true and the other will be thrown out" (M 21). These participants did not demonstrate an understanding of the role of prior knowledge, assumptions, theoretical commitments, and guiding frameworks in influencing scientists' interpretation of,

Table 2

A Summary of the Methods Group Participants' Pre- and Post-instruction NOS Views (n = 28)

NOS aspect	Pre-instruction % Informed	Pre-instruction: Illustrative quote of naïve views	Post-instruction % informed	Post-instruction: Illustrative quote of informed views
Tentative	25.0	Science is different from other disciplines of inquiry because there is an absolute truth and a right answer in science. (M 22)	50.0	Also, scientific theories and laws are similar in that they can also change. All scientific knowledge can change in the future, since we cannot be certain in science. (M 14)
Empirical	10.7	It is hard for me to think of the difference. I think science differs from religion because science can bring insight into questions like how something works, or what something is, but not why it exists. (M 11) Science is different from philosophy and religion in that it is about the facts as we observe them and not about opinions and interpretations. (M9)	60.7	Science is a way of thinking about the world. It is also a body of knowledge. It is different from other methods of inquiry because it is ultimately accountable to observations of nature. Sometimes observation can lead to different interpretations of the same natural phenomenon, but those different interpretations are subject to peer review and are eventually compared to the recorded observations. (M1)
Inferential (theoretical entities)	28.6	In this day and age of such advanced technology scientists are almost certain about the structure of the atom . . . They used strong microscopes such as electron microscope to clarify the structure. (M 27)	71.4	I believe this structure [of the atom] is a model. We can not see it. So, scientists had to do a lot of experiments and gather indirect evidence to come to this model which I think will be modified with new experiments and technologies as they become available. (M 4)
Creative and Imaginative	28.6	Scientists for the most part use scientific methods, logic and reasoning . . . Scientists need to use creativity because people are not interested in scientific findings, and a way is needed to make it appealing and meaningful. (M 24)	60.7	The most creativity and imagination is used when they [scientists] apply the data they found in their experiments to attempt to formulate theories explaining what they found. (M 17)
Theory-laden	17.9	Scientists reach different conclusions because of the enormous time that has passed since the dinosaurs extinction and no one was there to start with . . . So, they choose the piece of evidence that supports their own hypothesis. (M 8)	35.7	This is because of interpretation. The evidence can support one hypothesis or the other and this is related to the theory that the scientist is using and how he is approaching the puzzle of what killed all the dinosaurs. (M 2)

Table 2 (continued)

NOS aspect	Pre-instruction % Informed	Pre-instruction Illustrative quote of naïve views	Post-instruction % informed	Post-instruction Illustrative quote of informed views
Social and cultural	39.3	Ultimately, science is universal and scientific knowledge is the same everywhere, it touches every person in every culture. (M 12)	53.6	The direction of scientific study and funding is affected by cultural values . . . But more than that science itself is infused with cultural values. Scientists are influenced by the culture in which they live . . . Even though Copernicus had concrete scientific data and observations that the Earth was revolving around the sun, the rest of Europe did not waiver from its heliocentric view, since it was imbedded in the religious structure of the time . . . popular culture and beliefs did not allow new, revolutionary scientific ideas to take hold at first since it went against the culture. (M 17)
Theories *vs.* laws	10.7	A scientific law is a theory that has been tested and proven true to be accepted as a law. (M 6)	50.0	A scientific law describes how some aspect of the world behaves. For example, Newton's laws of motion describe how objects move. They do not say why something moves, they just predict how something moves. A theory, like evolution, is an explanation of the natural world, and explains a phenomenon. (M 26)
Nature and function of theories	28.6	We learn about theories even though they change because it would be better to learn something like how the dinosaurs became extinct than not to study the subject at all. (M 10) A scientific theory is just an educated guess. It has not been proven completely. (M 10) An example of a scientific theory is the Big Bang theory, which can never actually be tested. (M 12)	64.5	Theories help us explain the world around us and how it works. By studying theories and testing them we can reject them or come up with better theories and knowledge. Theories kind of guide the work of scientists because they need to know what they are looking for in the first place. (M 1) Even though a theory can change in the future it does not mean that it is not supported by evidence. On the contrary, a theory is well supported by evidence and connects a lot of observations. This is done by comparing the consequences of the theory with observations. (M 9)

evidence. Moreover participants' discussions of the empirical NOS were largely naïve. Participants seemed to believe that science was solely about the "facts" and dismissed the role that a host of other personal and social factors play in the generation of scientific knowledge. Yet, when distinguishing between science and other disciplines of inquiry, such as religion and philosophy, many participants failed to refer to the empirical NOS as a major distinguishing attribute. Rather, many participants noted that science was different because it involved physical evidence rather than opinion, or because it offered a way to reach "certain knowledge rather than speculation." Finally, 40% of the participants discerned a role for social and cultural factors in the scientific enterprise. However, participants' comments were mostly related to the role of social values and concerns in prioritizing funding for scientific research. Only two students believed that science itself was an enterprise embedded in a larger social and cultural milieu that impacted the very nature of the science that is done and the acceptance of scientific claims.

At the conclusion of the study, several desired changes were evident in the Methods group participants' NOS views. As evident in Table 2 (columns 4 and 5), these changes were mostly substantial and evident in the case of all target NOS aspects. Some changes, however, were less pronounced than others. In particular, little change was evident in participants' views of the tentative and theory-laden NOS, and the social and cultural embeddedness of science. By comparison, changes were pronounced regarding the inferential nature of scientific entities, the distinction and relationship between theories and laws, and the empirical NOS. Yet, much remains to be desired. A substantial percentage of the Methods group participants (ranging from 30 to 50%) still subscribed to naïve views of one of the target NOS aspects or another. Furthermore, only a handful of these participants demonstrated informed views that fit within a coherent and overarching framework for thinking about science. Inconsistencies and compartmentalization were evident in the views of many participants. For instance, it was not unusual for some participants to note that scientists use creativity in developing scientific knowledge and then ascertain that science is distinguished by a prescriptive universal "Scientific Method" that guarantees valid knowledge. Similarly, some participants still indicated that scientific knowledge is tentative and subject to change only to indicate later in their questionnaires that laws are different from theories because they are proven "true." Finally, the NOS views of a significant portion of the Methods group participants were not supported with examples from the history or practice of science, or were otherwise supported with inadequate examples. For instance, the change from a "flat to a round conception" of the Earth was the most commonly cited example of theory change.

By comparison, the post-instruction questionnaires of all four POS group participants indicated that they have internalized informed views of almost all target NOS aspects. Table 3 presents illustrative quotes of these participants' NOS views. Moreover, in contrast to the Methods group participants, the POS group participants' NOS views were (a) more articulate and indicative of deeper understandings of the issues involved, (b) supported with adequate examples from the history and practice of science (these examples included ones not discussed in the POS course), and (c) more consistent across the *VNOS–C* items and reflective of more coherent overarching frameworks for thinking about the scientific enterprise and the generation of scientific knowledge.

Perceptions of Teaching about NOS

In their second NOS-specific reflection paper assigned during Fall term, almost all participants admitted to having ascribed to several of the naïve NOS ideas that were addressed during Science Methods I:

> These misconceptions about science are something that I certainly believed at some point as a result of how science is taught. I have memorized the steps of the scientific methods on several occasions and I was taught that theories become laws when they are proven to be correct. (M 3, reflection paper)

However, the reactions of participants to the implications of their newly acquired understandings about NOS were all but consistent. About one third of participants (34.4%) noted that they need to address NOS in their own teaching:

> As a future science teacher, I must change these misconceptions in students' minds. My students need to understand that science is constantly changing; that it is not a mechanical process for answers; that creativity is often involved; that science is actually not dull! (M 23, reflection paper).

These participants believed that by addressing NOS in their teaching, they will end up encouraging more students to "go into science":

> Students should learn the real nature, usefulness, and beauty of science. As a teacher, I intend to set up labs so that creativity is encouraged and practiced . . . I will also communicate what science can and cannot achieve . . . In the long run, I think this will encourage more students to choose science as a career path. (M 11, reflection paper)

This latter view, nonetheless, was not shared by a majority of participants. About one third of participants (34.4%) expressed hesitance about presenting science to their students as a "chaotic process of discovery that follows no scientific method and that is conducted by creative people" (M 22, reflection paper). These participants were concerned that their authority as classroom teachers would be compromised if they were to present science as a less-than-certain endeavor:

Table 3

A Summary of the POS Group Participants' Post-instruction NOS Views (n = 4)

NOS aspect	Illustrative quote of naïve views
Tentative	Theories absolutely change over time! Theories change because science and all scientific knowledge is never certain, "conclusions" are only tentative. They can change when new data or new ideas surface or when scientists form new interpretations of what is already "known." (P 4)
Empirical	Science is . . . a set of processes of seeking to understand natural phenomena, to understand our past, and to predict what might happen in the future. Religion and philosophy have these same goals, but a major distinguishing factor is the empirical nature of science. Scientists are consistently seeking physical evidence for their conjectures. They do not rely on divine or purely logical arguments to support their ideas as religion and philosophy do. To some extent evidence separates science from religion and philosophy. (P 1)
	To my mind, science demands evidence and its claims should be consistent with observations of the natural world. An example would be what happened in the case of the "N" rays. I don't think religion or philosophy have this demand. (P 4)
Inferential	I think that this [atomic structure] is a viable model, but I am not certain that it is a mirror of reality . . . It is the most viable model we have had so far and there is a lot of evidence supporting it and there is merit to it. It is very useful. I am familiar with the process and steps they went through to get this model but at this point it's "truth" is somewhat like testing that cylinder you gave us in class that had the strings coming out of it. We can not really compare the insides, all we can do is observe it's tendencies and see if the theory produces the same effects. (P 2)
Creative and Imaginative	If no imagination was needed, induction would be possible and all the pieces of data should spell out the theory, but I realize this never happens. It takes creativity in order to know what data to collect and how to interpret it. I am so impressed with the patterns that scientists see in their data. I believe that that is one of the reasons that Einstein was so amazing. He could look at the same data or information that was available to others and he would see something different. (P 2)
Theory-laden	Science is not as objective as people would like to believe. When presented with evidence, people interpret it differently. The scientists involved in the debate about the extinction of dinosaurs each come from different paradigms. They interpret their evidence according to their own paradigm. Each group invariably will come across data / observations that do not fit within their framework. Sometimes this is dealt with by changing assumptions or interpretations in order to accommodate the new information without changing the structure. (P 1)
	Just because scientists have access to and use the same set of data to derive their conclusions doesn't mean that they are going to come up with the *same* conclusions . . . Their conclusions are surely consistent with the evince but also somewhat based on what type of training and education they have received, their personal belief system, their own imaginations, etc. (P 4)
Theories *vs.* laws	A scientific law is a statement or an equation that attempts to describe a phenomenon. A scientific theory is a statement or group of statements that attempts to explain this phenomenon. An example of a scientific law is Boyle's Law from which we know that if the volume of a gas is increased, then the pressure of the gas will decrease. However, it does not tell why this happens. The kinetic molecular theory, however, attempts to explain Boyle's Law. Thus, a scientific theory attempts to explain a phenomenon, while a scientific law just attempts to describe it. (P 3)

Table 3 (continued)

NOS aspect	Illustrative quote of naïve views
Nature and function of theories	Theories are likely to change, but they are still important. Theories give us an organized way to understand our observations and to use them to predict the outcomes in additional, similar situations. We do not know the absolute truth, though. We just accept our theories as "true" until something raises dissatisfaction with a theory *and* a better theory comes along. A good example is the phlogiston theory of matter. For years, the phlogiston theory was accepted as truth. Anomalous observations about the mass of burning metal caused many to be dissatisfied with the explanations of the phlogiston theory, but they could not reject it unless they had a better explanation. That came about in the oxygen theory of burning. (P 1)
	Although scientific theories do change, we learn them and teach them because they are valid and substantiated arguments that predict, explain, and provide conceptual frameworks for further research in a certain area. (P 4)
Social and cultural	Science is a community. Science is not practiced in isolation. While some observations related to science may transcend society (a ball falls back to earth when you throw it, the sun rises every morning, the moon cycles through phases, if you mix baking soda with vinegar it foams up), but every society will have its own terms and its own explanations for the phenomena. Science is dictated by the values and beliefs within a society. Science is not practiced in an ivory tower, and it is not isolated from every day life. The scientist is influenced by his religious beliefs, societal pressures and norms, and personal beliefs. The scientist is expected to operate within his scientific community, to have discourse with community members, and to work together. To say that science is outside of culture is to deny the fact that the scientist himself is a part of a larger culture, and a functioning member of a scientific community. It is not possible for science to be unaffected by such things. (P 1)

> Imagine teaching a class where you have to say "This is a law, now a law is not necessarily something that should be true all the time, because it could potentially be changed." How are you ever going to get the students' attention or have them do all the work if you say science is not a sure thing? (M 25, reflection paper)

An additional 25% of participants noted that even though they were convinced that more accurate views of NOS should be taught to students, they believed that this would not be possible. These participants cited one of three reasons to justify this belief: (a) the target NOS ideas would not be of interest to students, (b) NOS ideas are generally too abstract and complicated for students to understand, and (c) given the amount of content that teachers have to cover, little time will be left to address topics such as NOS:

> I seriously think that these ideas about the nature of science might be too difficult for school students to understand. I think it is okay to explain science as it has been taught in the past (it gives them a structured sense of science), even if we convey some erroneous ideas about the nature of science. It is the job of later education to correct these ideas and give students a more accurate view of science. (M 18, reflection paper)

> I do not think, though, that I will have the time to teach them [future students] about the nature of science concepts. I will barely have time to cover all the other basic stuff that is required of me (like photosynthesis, chemical reactions, laws of motions, . . .). (M 8, reflection paper)

The above results are by no means new or unusual in the case of preservice secondary science teachers (see Abd-El-Khalick et al., 1998). Helping teachers to internalize informed views of NOS does not automatically translate into them internalizing its importance as a curricular goal or realizing that it could be taught as part of the "regular" science curriculum. These results, nonetheless, provide the backdrop for understanding the importance of the results obtained in the case of the POS group participants.

In their first two reflection papers, the perceptions articulated by the POS group participants regarding the implications of the philosophical and NOS ideas discussed in the course to science teaching were generally not different from those of the Methods group participants. These reactions primarily focused on *whether* it is possible, and *how* to teach students about the specific NOS ideas they have just "learned." However, starting with the third reflection paper, a shift was evident in the thinking of 3 of the 4 POS group participants. They went one significant step further and started to contemplate the changes in their teaching practices, including discourse, behaviors, and assignments, that are entailed by the sort of NOS understandings they have internalized. This important shift in thinking is evident in the following representative quotes:

> In my previous reaction papers I was, for the most part, preoccupied with thinking about incorporating things I have learned from this class into my own teaching. In a sense I was thinking about how to teach my own students what I am learning in this class. Now I realize that this might have been a naïve way to think about this matter. After all, many of these ideas are too complex and I struggle with trying to understand them myself. My thinking now is more on how these ideas about how science really works will change the way I teach; the way I talk about science; the kinds of labs my students will do; and the way I will ask them to think about science. (P4, reflection paper #3)

> After doing all these readings, I believe I understand why many philosophers of science would agree that the science that is taught in schools is not the science that is practiced by the scientific community. In the science I have learned, science was the "truth". Never questioned. Never debated. My teachers did not use words like "scientists believed" so and so, or they "think" so and so. It was always a statement of the facts. In my own teaching, I need to be very careful about the language and terms I use. Probably terms about truth and certainty should not be used when teaching science. (P1, reaction paper #4)

<u>Instructional Planning Related to NOS</u>

Consistent with previous research findings (e.g., Abd-El-Khalick et al., 1998; Bell et al., 2000; Lederman et al., 2001), the translation of participant preservice teachers' acquired NOS understandings into instructional planning related to NOS was minimal. The lesson plans of only 4 of the 28 participants in the Methods group (14%), who received explicit reflective NOS instruction, included explicit instances of planning to teach about NOS. Of these participants, three were undergraduates and one was a graduate student. These participants' lesson plans included specific NOS-related instructional objectives, such as "The students will be able to discuss the level of authority that science allows (science is never 100% absolutely the truth)" (M 11, lesson plan #2), and "Students will be able to defend the validity of the constructed model based on the agreement of its predictions with the observations of the phases of the moon that they made" (M 1, lesson plan #1). Two of these participants planned to teach about the distinction between observation and inference, and the empirical and tentative NOS. The third participant addressed the explanatory and predictive nature of scientific models and the process of validating such models. The fourth participant explored the interactions between science and social values through planning for her students to investigate and discuss the priority given to funding research on AIDS.

The NOS-related instructional objectives were coupled with relevant activities and/or discussions. For instance, one of the aforementioned four participants simply chose to "lecture" about NOS for the better part of his lesson. Another created a scenario involving a black-box activity, which was different from those activities presented in the methods courses. According to this scenario "scientists unearthed a mystery box . . . . with a set of extremely valuable and fragile items that are covered with a cloth" (M 11, lesson plan #2). Students were expected to feel the items through the cloth without ever removing the cloth, draw inferences about the nature of the items, and come up with a story about the event that must have involved these items. The activity was followed with a set of questions designed to help students discern the differences between observation and inference, and realize the tentative nature of their stories given the available evidence.

To be sure, the lesson plans of several Methods group participants included instructional objectives that were related to science process skills. Indeed, 11 of the 28 Methods group participants (39%) planned instructional activities aimed at providing students with opportunities to—among other things, draw conclusions based on observations, interpret tabular data and graphs, control variables, and design experiments. These instructional activities, however, lacked any explicit and/or reflective components that addressed relevant NOS aspects, such as the variety of methods that could be used to reach evidence-based answers to questions of interest, the limitations associated with the use of positive instances to ascertain the validity of a hypothesis, or the role of expectations, prior knowledge, and theory in influencing the design of experiments. As such, these participants failed to capitalize of these opportunities to plan to teach their students something about the nature of generating and validating scientific claims.

By comparison, 2 of the 4 POS group participants planned to teach about NOS. Like their counterparts in the Methods group, they included NOS-specific instructional objectives and coupled them with instructional activities and explicit discussions. One participant planned to teach students about the inferential and tentative nature of scientific claims using a black-box type activity, while the other planned for her students to investigate the historical development of major geological theories in the context of a unit on the theory of plate tectonics. This latter participant aimed to teach her students about tentativeness of scientific theories and the role of reinterpreting evidence in theory change.

Even though the other two POS group participants did not explicitly plan to teach about NOS, a noteworthy aspect of the lessons they planned during the latter half of Spring term (lesson plans 3 and 4) was their use of language that was consistent with accurate conceptions of NOS. When their lesson plans included objectives targeting science process skills, such as designing experiments and testing hypotheses, these two participants included questions or explicit statements that alerted students to some NOS-related ideas, including that positive evidence does not "prove" a hypothesis or that having others check the results of one's experiment would "help reduce the bias" inherent in any one individual's interpretations and conclusions. Even though these instances were few in number, they were consistent with the shift that was evident in the POS group participants' comments regarding the implications of learning about NOS for their own teaching. As noted above, these participants shifted their thinking from a preoccupation with whether secondary students could understand the NOS ideas they were learning about in the POS course and how to best teach secondary students about these ideas, to the realization that these NOS ideas have implications for the way these participants would teach science in their future classrooms. Moreover, these instances indicate that having deep understandings of NOS potentially enables prospective teachers to capitalize on certain instances (e.g., when teaching science process skills) and teach about NOS in the context of "regular" science sessions versus ones specifically intended to teach about some aspect of NOS (which many teachers view as an add-on to their teaching). This was not the case with the Methods group participants. As noted above, many of these participants included science process skills objectives in their lesson plans but none planned to utilize these instructional episodes to teach something about NOS.

Discussion and Implications

This study indicates that the investigated POS course resulted in deeper understandings of NOS on the part of participants. It should be noted, however, that (a) participants joined with the POS course after having been explicitly sensitized to the target NOS aspects in the Science Methods I course, and (b) the POS course was specifically designed to influence participants' views of these aspects and was coupled with relevant readings from history and practice of science. The present results, thus, cannot be generalized to other POS courses. More importantly, exposure to POS coupled with explicit reflective cues regarding the implications of the course content for science teaching resulted in moving participants beyond the customary discourse of our previous participants (e.g., Abd-El-Khalick et al., 1998; Lederman et al., 2001) regarding whether it is possible and how to teach specific NOS ideas to K-12 students, to the present participants thinking about their own teaching behaviors in relation to NOS. Finally, the genesis of a NOS PCK was evident through the POS group students' use of specific examples from history and practice of science in their discourse, and plans to teach, about NOS. However, these results should be viewed with caution given the relatively small number of prospective teachers enrolled in the POS course. This study indicates that more concerted and extended efforts that go beyond a few hours of NOS-related instruction in a science methods course should be undertaken if we desire science teachers to address NOS instructionally. Finally, the significant question of whether the NOS views and understandings of the POS group students will translate into actual classroom practices remains to be answered. This question will be pursued after these students go into teaching.

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