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Developing deeper understandings of nature of science: the impact of a philosophy of science course on preservice science teachers' views and instructional planning

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RESEARCH REPORT

Developing deeper understandings of nature of science: the impact of a philosophy of science course on preservice science teachers' views and instructional planning

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This study aimed to assess the influence of a philosophy of science (POS) course on science teachers' views of nature of science (NOS), perceptions of teaching about NOS, and instructional planning related to NOS. Participants were 56 undergraduate and graduate preservice secondary science teachers enrolled in a two science-methods course sequence, in which participants received explicit, reflective NOS instruction. Ten of these participants were also enrolled in a graduate survey POS course. The *Views of Nature of Science Questionnaire — Form C* coupled with individual interviews was used to assess participants' NOS views at the beginning and conclusion of the study. Participants' lesson plans and NOS-specific reflection papers were analysed to assess the impact of the POS course on their instructional planning related to, and perceptions of teaching about, NOS. Results indicated that, compared with participants enrolled in the methods courses, the POS course participants developed deeper, more coherent understandings of NOS. Substantially more of these latter participants planned explicit instructional sequences to teach about NOS. Additionally, the POS course participants' discourse regarding NOS progressed from a preoccupation with the technical, to a concern with the practical, and, finally, to a focus on the emancipatory. Their views of teaching about NOS in their future classrooms went beyond the customary discourse of whether pre-college students should or could be taught about NOS, to contemplating changes they needed to bring about in their own teaching behaviour and language to achieve consistency with their newly acquired NOS understandings.

Introduction

The objective of helping pre-college students develop informed views of nature of science (NOS) has been a central goal for science education during the past 85 years (Abd-El-Khalick et al. 1998). Presently, this objective represents a focal and shared goal for major reform efforts in science education (for example, American Association for the Advancement of Science [AAAS] 1990, Millar and Osborne 1998, National Research Council [NRC] 1996). However, research has consistently shown that pre-college students have not attained the desired understandings of NOS (Duschl 1990, Lederman 1992). Similarly, science teachers were found to harbour several naive NOS views (for example, Abd-El-Khalick et al. 1998, Billeh and Hasan 1975, Bloom 1989, King 1991). To mitigate this state of affairs, several attempts were undertaken to improve teachers' NOS views (for example, Akindehin 1988, Billeh and Hasan 1975, Ogunniyi 1983, Olstad 1969, Scharmann and Harris 1992). In a comprehensive review, Abd-El-Khalick and Lederman (2000a) concluded that these efforts were generally not successful in helping teachers

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develop understandings that would enable them to effectively teach about NOS. Nonetheless, they noted that an explicit reflective approach to enhancing teachers' conceptions (for example, Abd-El-Khalick et al. 1998, Akerson et al. 2000, Shapiro 1996) was relatively more effective than an implicit approach that utilized hands-on or inquiry science activities lacking explicit references to NOS (for example, Barufaldi et al. 1977, Haukoos and Penick 1983, 1985, Riley 1979).

Yet, even though an explicit reflective approach undertaken within science-methods courses was successful in positively influencing teachers' NOS views, the translation of these views into instructional practices was, at best, limited and mediated by several factors (for example, Abd-El-Khalick et al. 1998, Bell et al. 2000). Among these factors was science teachers' *depth* of understanding of the target NOS aspects. Abd-El-Khalick and Lederman (2000a) argued that to be able to effectively teach about NOS, teachers need to have more than a basic knowledge and understanding of some NOS aspects. They 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 teaching about NOS with some examples or 'stories' from history of science, and design science-based activities to render the target NOS aspects accessible and understandable to pre-college students. In other words, science teachers need to have some level of NOS pedagogical content knowledge.

There is a limit to what can be done within the context of science teacher education programs given their already extensive agendas. Thus, any efforts undertaken within these programs to help prospective teachers develop deep understandings of NOS need to be augmented with coursework in other disciplinary departments. Intuitively, courses 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 teachers develop more informed conceptions of NOS (see Matthews 1994, O'Brien and Korth 1991, Robinson 1969, Scheffler 1973). However, despite the longevity of these arguments, there seem to be no empirical studies in the science education literature that systematically examined the influence of POS courses on teachers' NOS views or instructional practices. Thus, this study aimed to assess the influence of a POS course on preservice secondary science teachers' views of NOS, perceptions of teaching about NOS, and instructional planning related to NOS.

Nature of science

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 paper instead of the more stylistically appropriate 'the NOS' is intended to reflect my lack of belief in the existence of a singular NOS or general agreement on what the phrase specifically means (Abd-El-Khalick 1998). This lack of agreement should not be disconcerting or surprising given the multifaceted, complex, and dynamic nature of the scientific enterprise. Nonetheless, there is an acceptable level of generality regarding NOS that is accessible to pre-college students and at which virtually no disagreement exists among experts (Abd-El-Khalick et al. 1998).

Among the aspects of NOS that fall under this level of generality are that scientific knowledge is: tentative (subject to change), empirical (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 concepts and explanations), and socially and culturally embedded. Two additional aspects are the distinction between observation and inference, and the functions of, and relationship between, scientific theories and laws. These NOS aspects, which were targeted in this study, have been emphasized in recent science education reform documents (for example, AAAS 1990, NRC 1996). For further discussion of these NOS aspects the reader is referred to Abd-El-Khalick et al. (2001). In this regard it should be emphasized that these NOS aspects are not conceived of as disparate, but rather as integral components of an epistemology in which scientific knowledge is produced through critical, negotiated, and collaborative inquiries that are propelled by scientists' imaginations and bound only by their observations of the natural world.

Method

This study was exploratory and interpretive in nature (LeCompte and Priessle 1993). Data collection was continuous and spanned the duration of the study. Figure 1 presents an overview of the study's participant students and courses, timeline, procedures, instruments, and data sources. As is evident in figure 1, numerous data sources were used to answer the guiding research questions: What is the impact of a POS course compared with NOS instruction undertaken in the context of a science methods course, on preservice secondary science teachers': (a) views of the target aspects of NOS? (b) perceptions of teaching about NOS in their future classrooms? and (c) instructional planning related to NOS?

Participants

The present study was replicated with two cohorts of preservice secondary science teachers over the course of two consecutive academic years. Participants in each cohort were 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 in the USA. Table 1 presents the profile of participants in each cohort. In this regard, it should be noted that, with two exceptions, 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.

Each iteration of the study spanned two semesters. During the fall term, each cohort's participants were enrolled in the first science methods course (Science Methods I). During the spring term, all participants were enrolled in the second methods course (Science Methods II). Additionally, during the spring term, four and six of the graduate participants in cohort I and cohort II were enrolled in a graduate survey course of POS, respectively (see table 1 and 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

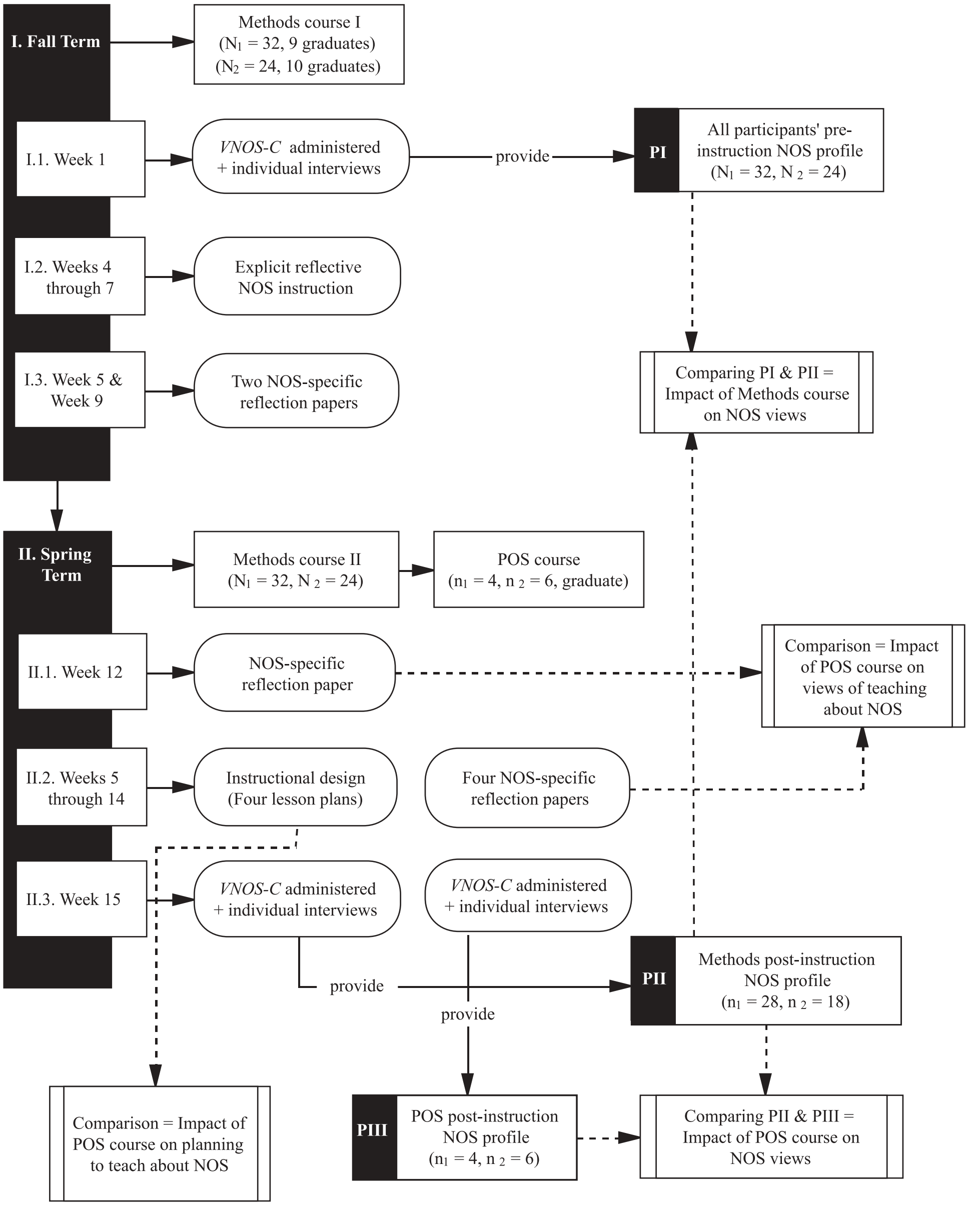

Figure 1. An overview of the study' participant students and courses, timeline, instruments, and data sources. (The subscripts 1 and 2 refer to cohorts I and II respectively.)

students to teaching science in a diverse society. The course explores the goals of science education past and present, contemporary views 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 spanning weeks four to seven of this course (see figure 1, I.2), a

Table 1. Profile of participant preservice secondary science teachers.

Attribute	*Cohort I*	*Cohort II*
Number enrolled in methods courses	32	24
Female	20 (62%)	17 (71%)
Male	12 (38%)	7 (29%)
Age (years)		
Range	19–25	20–27
Mean	20.9 (standard deviation, 1.3)	21.7 (standard deviation, 1.7)
Class standing		
Junior	3 (9%)	2 (8%)
Senior	20 (62%)	12 (50%)
Graduate	9 (28%)	10 (42%)
Graduates enrolled in POS course	4	6
Female	3 (75%)	3 (50%)
Male	1 (25%)	3 (50%)
Mean age (years)	22.0	23.8

set of 15 generic activities and three readings were used to provide participants with opportunities to examine and reflect on their NOS views, and to explicitly introduce them to the target aspects of NOS. Detailed descriptions of these activities can be found elsewhere (Lederman and Abd-El-Khalick 1998). A whole-class discussion followed each activity and involved students in active discourse concerning the target NOS aspects.

Also, in Science Methods I, students 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, I.3), was in reaction to McComas (1996). Participants were asked to discuss the NOS ideas presented in this reading and compare them with their own views. This paper aimed to help students clarify and confront their own views of NOS. For the second reflection paper, participants read the prologue for Penrose's (1994) *Shadows of the Mind: A Search for the Missing Science of Consciousness*, and answered the following question: '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 scientist. The father and Jessica go into a cave to collect plant specimens. While inside, Jessica wonders what would happen if she, her father, and others were trapped inside the cave. Eventually, she asks, '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: 2). The ensuing conversation focuses on how we 'know' and how 'valid' is our knowledge, as Jessica's father tries to explain how much they could learn about the outside world just by observing whatever shadows that might form on their cave walls. This reflection paper was written following the conclusion of NOS instruction and aimed to provide students an opportunity to reflect on their newly acquired NOS understandings (if any) and apply them in a novel context.

Science Methods II engages students in a set of 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 future classrooms. Activities are followed with structured discussions aimed at getting participants to reflect on the sort of learning experiences they have engaged, discern how these experiences differ from the traditional science teaching that many of them have experienced, and articulate the benefits and burdens of these espoused teaching approaches. The course also helps students 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 (see figure 1, II.2).

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 2 presents an overview of the topics and case studies addressed in the course, along with some illustrative readings. The course aims to help students develop deep understandings and critical views of NOS and their implications for science teaching and learning at the curricular, pedagogical, and instructional levels. To help achieve these goals, students were required to write four extended reflection papers in which they discussed the major ideas addressed in a set of sessions, compared these ideas about science with their own views, assessed any changes in their NOS views, and discussed the ways in which, if any, the presented ideas were related to teaching pre-college science (see figure 1, II.2).

The experiences detailed above were the only explicit encounters that students had with NOS during the fall and spring terms. They were not enrolled in any other relevant courses (e.g. courses in history, philosophy, or sociology of science). 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, perceptions of teaching about NOS, and instructional planning related to NOS (see figure 1, boxes with dashed lines).

Procedure

The *Views of Nature of Science Questionnaire — Form C* (VNOS–C) (Abd-El-Khalick et al. 2001) was used to assess participants' views of the target NOS aspects at the beginning of the fall term and end of the spring term. Given the study's concern with the meanings that participants ascribed to the target NOS aspects, it was imperative to avoid misinterpreting their responses to the *VNOS–*

Table 2. Overview of the philosophical topics and accompanying historical case studies addressed in the POS course.

Topic(s)	*Illustrative readings*
Induction and its failings, Bayesianism, Popper's falsificationism and its failings	Selections from Russell (1959), O'Hear (1989), and Popper (1992) Case study: Boyle's law (Harre' 1983)
The Duhem–Quine thesis and underdetermination	Duhem (1998), Quine (1998) Case study: The dinosaur extinction controversy (Alvarez and Azaro 1990, Courtillot 1990, Glen 1990, 1994)
Observation, theory, and incommensurability: Kuhn on normal science, revolutions and their resolution, 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) Case study: the Michelson–Morely experiment (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, 1998b), Thagard (1998) Case study: marginal science (Mauskopf 1996)
Science as social knowledge	Selections from Bloor (1976) and Longino (1990) Case studies: cold fusion and verification of relativity theory (Collins and Pinch 1993)
Feminist approaches to science	Giere (1998), Haraway (1978), Keller (1997) Case study: Hominid evolution (Hrdy 1986, Lovejoy 1981)

C. Thus, individual semi-structured interviews were used to establish the validity of the questionnaire by ensuring that the researcher's interpretations of participants' written responses were congruent with those elucidated by participants during the interviews. Twenty-five percent of the participants in each cohort were randomly selected for interviewing (eight from cohort I and six from cohort II).

One-half of these participants were interviewed following the first administration of the *VNOS–C* and the other half following the second administration of the instrument. This latter procedure was used to avoid introducing the pre-instruction interview, which could have served as a treatment, as a confounding variable that could influence participants' responses during the post-instruction interview. 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 their pre-instruction 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 audiotaped and transcribed for analysis. Finally, participants' NOS-specific reflection papers from all three courses, and their lesson plans from the spring science-methods course, were collected 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 endeavour and teaching about NOS, participants were not given any cues whatsoever for choosing topics or objectives for their lesson plans.

Data analysis

The author analysed 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 ensure 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. To ensure clarity, data analyses related to each research question are presented separately. The following presentation reflects the order in which the three stages of data analyses were conducted.

Impact of POS course on participants' instructional planning related to NOS. All participants' lesson plans were searched for evidence to assess whether they 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 aspects of NOS. 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 (see Abd-El-Khalick et al. 1998). Also, activities that were consistent with a particular view of science, but did not explicitly focus students' attention on a target NOS aspect, were not considered explicit instances. For example, a planned 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. To assess the impact of the POS course on students' planning, the documented explicit NOS teaching instances for the Methods group ($n = 46$) and POS group ($n = 10$) were compared and contrasted.

Impact of POS course on participants' perceptions of teaching about NOS. Participants' NOS-specific reflection papers were examined to gauge changes in their NOS views and assess their views regarding teaching about NOS. The reader is reminded that the Methods group participants tackled the question on addressing NOS in their future classrooms in a reflection paper written toward the end of the Science Methods II course (see figure 1, II.1), while the POS group grappled with the same question throughout the POS course (see figure 1, II.2). The results of analysing the reflection papers were clustered by group of interest (i.e. the Methods group versus the POS group) and compared and contrasted to assess the impact of the POS course on students' perceptions of teaching about NOS in their future classrooms.

Impact of POS course on participants' views of NOS. Participants' *VNOS–C* questionnaire responses were examined during the last phase of data analysis. Analysis started with the pre-instruction questionnaires of the 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 our interpretations of participants' views as elucidated on the *VNOS–C* were congruent with those they expressed during individual interviews. This procedure was repeated with the post-instruction questionnaires and interview transcripts of the other interviewees resulting in similar congruency. Next, all pertinent questionnaires were analysed to generate pre-instruction and post-instruction profiles of the NOS views of a certain group of participants (i.e. Methods group, POS group, graduate participants, undergraduate participants). In these analyses, each questionnaire was used to generate a summary of a participant's views of the target NOS aspects. The summaries for a certain group of students were searched for patterns, which were then checked against confirmatory or contradictory evidence in the data and modified accordingly. Several rounds of category generation, confirmation, and modification were conducted to satisfactorily reduce and organize the data and generate a profile of the NOS views for a group of participants. Next, the pre-NOS and post-NOS profiles for the Methods and POS group participants were systematically compared and contrasted to assess the impact of the POS course on students' views of NOS.

It should be noted that a conscious decision was made to analyse students' lesson plans prior to examining their NOS-specific reflection papers and *VNOS–C* responses to avoid biasing the results of analysing these plans. Examining students' NOS views and statements regarding teaching about NOS prior to analysing their lesson plans could have created a mindset that might have lead us to read into some of their 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.

Finally, it should be noted that students in the POS group (i.e. those enrolled in the Methods and POS courses) were graduate students, while the greater majority of the Methods group students (i.e. those 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, all of the aforementioned comparisons were also conducted with three additional groups: graduate students in the Methods group (n = 9), undergraduate students in the Methods group (n = 37), and students in the POS group (n = 10) (see table 1).

Results

Results for the two participant cohorts were consistent in almost all respects. Differences were generally not substantial. Thus, in the following sections, the results from the two iterations of the study are combined (for instance, percentages of participants with informed views of certain NOS aspects represent averages across the two cohorts). Instances in which substantial differences were evident in the results obtained for the two cohorts will be explicitly pointed out. Also, comparisons between the Methods group participants less the graduate students, the graduate students enrolled in the methods courses only, and the POS group all allowed ruling out class standing (i.e. undergraduate versus graduate) as a confounding variable in the present study. In the case of both cohorts, views of NOS and teaching about NOS, and related instructional planning of graduate students in the Methods group, were not systematically or substantially different from those of the undergraduate students. In what follows, alphanumeric codes are used to refer to participants: The letters 'M' and 'P' refer to students in the Methods and POS groups, respectively, and the Roman numerals 'I' and 'II' refer to participants in the first and second cohorts, respectively. Each code includes a numeric that refers to an individual participant.

Participants' views of NOS

Pre-instruction NOS views. 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 students held naive views of several of the target NOS aspects. Consistent with prior research findings (see Abd-El-Khalick and Lederman 2000a), 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':

> A law is a theory that is universal and … known to be sure in all cases, it has been proven … A theory is an idea based on evidence but not known to be true for all cases, it is not proven. (MII 14)

An alarming majority of participants (73%) seemed to believe that scientific knowledge is not tentative. Some of these participants articulated this view explicitly: 'Science is different from other disciplines of inquiry because there is an absolute truth and a right answer in science' (MI 22). Other students conveyed this belief in their responses to various *VNOS–C* items. For instance, while almost all students indicated that scientific theories do change with the advent of new evidence and technological development, a large majority believed — as represented in the earlier quote — that laws are 'sure in all cases' or 'facts' and not amenable to change because they are 'proven to be true'. 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 naive view of theories as an intermediate step in the generation of 'true' scientific knowledge (i.e. laws and facts).

Indeed, about 70% of students did not demonstrate informed views of the well-substantiated nature of theories. 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': 'A theory is an idea that attempts to describe an unknown phenomenon. It is … merely how one scientist perceives the phenomenon' (MII 3). A majority of participants (70%) also lacked an understanding of the logic of testing scientific theories. These students did not seem to understand that only indirect evidence could be used to support theories. Alternatively, they indicated that a 'theory cannot be tested. For example, 'we will never know what killed the dinosaurs because no one was there and scientists cannot travel back in time to witness the events that led to the extinction of the dinosaurs' (PI 2). Similarly, participants did not articulate informed views of the explanatory and predictive functions of theories, or their crucial role as frameworks for guiding research. Many students simply argued that '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' (MI 10).

Only about 30% of participants articulated informed views of the inferential, and creative and imaginative NOS. For instance, 71% of participants indicated that scientists were 'certain' about atomic structure because 'high powered microscopes' were used to discern this structure: '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 microscopes to clarify the structure' (MI 27). 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', might have transferred into the aforementioned participants' (uninformed) discussions of theories whereby many indicated that scientific 'theories can't be tested because of the absence of direct observable evidence for them' (PII 1). Also, even though the majority of students noted that scientists use creativity and imagination in their work, only 30% 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 to the public: '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' (MI 27).

A minority of students (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' (MI 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 evidence. Rather, they believed that scientists use different 'pieces' of the available evidence to support a certain claim: 'Scientists reach these different conclusions because the extinction happened a long time ago and no one was around back then … So, each scientist chooses the pieces of evidence that support his own hypothesis' (PI 2).

Moreover, participants' discussions of the empirical NOS were largely naive. They 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 and validation of scientific knowledge: 'Religious and philosophical fields rely heavily upon ideas, opinion, human thought, and perception. Whereas, in scientific fields facts are used to reach definite conclusions' (MII 17). Yet, when distinguishing between science and other disciplines of inquiry, such as religion and philosophy, about 50% of 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, a majority of participants (60%) believed 'that science is universal. No matter which country or even continent you're in, science is the same. Though we all may have different names for things, the science is the same' (MII 24). Only 40% of students discerned a role for social and cultural factors in science. However, participants' comments were mostly related to the role of social values and concerns in prioritizing funding for scientific research. Only four 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.

Post-instruction NOS views. At the conclusion of the study, several desired changes were observed in the Methods group participants' views. As evident in the percentages of informed post-instruction views of the target NOS aspects and associated illustrative quotes presented in table 3, these changes were mostly substantial and observed in the case of all eight NOS aspects. However, some changes were less pronounced than others. In particular, little change was evident in students' 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 60%) still subscribed to naive views of one of the target NOS aspects or another. Furthermore, only a handful of these students 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. These results were consistent with previous research studies in which explicit reflective NOS instruction undertaken within the context (and confines) of science-methods courses was used to help science teachers develop informed views of NOS (for example, Abd-El-Khalick et al. 1998; Akerson et al. 2000).

By comparison, the post-instruction questionnaires of all 10 POS group participants indicated that they have internalized informed views of almost all target NOS aspects. Table 3 presents illustrative quotes of these students' views. Moreover, in contrast to the Methods group participants, the POS group participants' NOS views

Table 3. A summary of the methods and POS group participants' pre-instruction and post-instruction informed NOS views.

		Methods group post-instruction informed views (n = 46)		POS group post-instruction informed views (n = 10)[a]
NOS aspect	*% informed pre-views (n = 56)*	*Illustrative quote*	*%*	*Illustrative quote*
Theories versus laws	10.7	'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 … of a phenomenon' (MI 26)	53.6	'These are different sorts of scientific knowledge. Theories are inferences and explanations about why certain events or data are observed. Scientific laws are accounts of observations and their relationships. Boyle's Law depicts the relationship between pressure and temperature. Kinetic molecular theory posits the existence and behavior of unobserved (and unobservable???) particles to explain the relationship described in Boyle's law' (PII 3)
Tentative	26.8	'Science is different from religion because in religion generally people think of there being one true and right answer … There can be no absolute true things in science. The only way something can be proven to be absolute is if there is no counterexample. We can never know that there isn't a counter example; we can only know that there is a counterexample when we come upon one … Therefore, scientific knowledge can change at any time' (MII 8)	58.9	'Science is a social endeavour, the goal of which is to discover patterns in the natural world and explain them. The whole body of knowledge associated with science is tentative. Often the changes in this body of knowledge come about as small modifications of principles, theories, and laws in light of new evidence or reinterpretation of existing evidence. However, large shifts in the way the scientific community thinks about phenomena also occur, sometimes because of new ideas or ways of thinking' (PII 5)
Inferential (theoretical entities)	28.6	'Scientists have not seen the atom. They can't know without doubt its exact structure. They can, however, formulate theories about the atomic structure … by inference from experimental evidence. Atomic theories or models are subject to change and probably will change with time and improvements in research technology' (MII 14)	71.4	'Species, like many concepts in science, is a concept which we impose on nature, because we need categories and labels to think and communicate about natural phenomena … It is a theoretical concept … There is no unique or absolute demarcation of the species we find in nature. For instance, not all breeds of domestic dogs could produce viable offspring. A male St. Bernard and a female Chihuahua could not interbreed, not the natural way, and perhaps not at all. Yet there are organisms in gray areas, like beagles, that could breed with either one of them!' (PII 2)

Table 3. Continued.

		Methods group post-instruction informed views (n = 46)		*POS group post-instruction informed views (n = 10)*[a]
NOS aspect	*% informed pre-views (n = 56)*	*Illustrative quote*	*%*	*Illustrative quote*
Empirical	10.7	'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' (MI 1)	60.7	'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' (PI 1)
Nature and function of theories	28.6	'Theories provide explanations of how natural phenomena work. Theories provide guidance for scientists because they help them focus their studies and experiments. By working with theories and modifying them by collecting more and better data, scientists end up with better knowledge' (MII 16)	66.1	'Scientific theories do change. 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 … We learn them [theories] and teach them because they are valid and substantiated arguments that predict, explain, and provide conceptual frameworks for further research in a certain area' (PI 4)
		'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' (MI 9)		'Theories are systems of ideas that explain a whole lot of observations of one phenomenon, and sometimes of several different phenomena. Theories provide us with tools or manageable ways of organizing and understanding empirical observations and making accurate predictions about future occurrences of many phenomena' (PII 6)

Table 3. Continued.

		Methods group post-instruction informed views (n = 46)		POS group post-instruction informed views (n = 10)[a]
NOS aspect	*% informed pre-views (n = 56)*	*Illustrative quote*	*%*	*Illustrative quote*
Creative and imaginative	30.4	'Scientists have to use their imagination throughout their investigations … They have to use their creative minds to plan and design their investigations … But a more demanding use of their creative minds happens when they analyse their findings and come up models and theories to explain what their findings mean' (MII 2)	60.7	'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' (PI 2)
Theory-laden	17.9	'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' (MI 2)	35.7	'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' (PI 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 evidence but also somewhat based on what type of training and education they have received, their personal belief system, their own imaginations, etc.' (PI 4)

Table 3. Continued.

NOS aspect	% informed pre-views (n = 56)	*Methods group post-instruction informed views (n = 46)* Illustrative quote	%	*POS group post-instruction informed views (n = 10)*[a] Illustrative quote
Social and cultural	39.3	'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' (MI 17)	60.7	'Science is a community. Science is not practised 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 practised 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' (PI 1)

[a] With the exception of two participants who expressed inarticulate views of one NOS aspect (the social and cultural NOS), all the POS group participants articulated informed views of all target NOS aspects.

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 and validation of scientific knowledge.

Perceptions of teaching about NOS

Methods group participants. In their second NOS-specific reflection paper assigned during the fall term (see figure 1, I.3), almost all participants admitted to having ascribed to several of the naive 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. (MI 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 (35.7%) noted that they need to address NOS in their own teaching:

> Due to these misconceptions of science, students are not allowed to appreciate science. They are not allowed to experience the discovery of science and therefore they become disinterested and misled. The myths of the nature of science began in the classroom and must end in the classroom … In my own classroom I will guide my student to achieve a better understanding of the nature of science as the first step to increase their appreciation of science. (MII 13, 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 practised … 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. (MI 11, reflection paper)

This latter view, nonetheless, was not shared by a majority of participants. About one-third of participants (34.0%) expressed hesitance about presenting science to their students as a 'totally messy and disorganized process not governed by procedures for doing investigations and rules for drawing exact conclusions' (MII 16, 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 endeavour:

> 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? (MI 25, reflection paper)

An additional 25% of the Methods group 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. (MI 18, reflection paper)

> I do not see how the reality of the classroom will allow me to teach my students about the nature of science concepts … I am interested in teaching AP chemistry and there is a lot of materials to cover in this course. I am fully aware of how much time this material will take to cover and I know that I will be held accountable for getting my students through the whole course. (MII 12, reflection paper)

These perceptions were not appreciably different toward the end of the study, as was evident in the Methods group participants' NOS-specific reflection paper that they wrote toward the end of Science Methods II (see figure 1, II.1).

The results reported here are by no means new or unusual in the case of preservice secondary science teachers (see Abd-El-Khalick et al. 1998, Bell et al. 2000). Having internalized some informed views of NOS does not automatically translate into preservice teachers 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.

POS group participants. Two significant features characterized the first two reflection papers that these participants wrote for the POS course: (a) a preoccupation with their (sometimes painful) attempts to make sense of the very philosophical ideas that were invoked in the course, and (b) a focus on what these ideas entailed for K-12 science curriculum. First, these initial papers embodied participants' struggles in coming to terms with the philosophical concepts that they came into contact with in relation to their own conceptions of NOS. The following quote sheds light on one participant's struggle to sort out — albeit with little success — some of the ideas that were discussed during the first two sessions of the course:

> Some of the major ideas addressed in these first readings of the semester raise arguments that demonstrated the difficulty of the philosophy of science. The Baconian idea that one can use means of induction in a presuppositionless state to develop theories is a statement I found quite troubling. I first thought that Duhem raised some of the reasons I found it troubling … Nevertheless, Duhem suggests the experimental method consists of approaching a theory or experiment without prejudice whether the theory is your own or someone else's. This idea seems to me to be similar to the presuppositionless idea. But right after that, Duhem seems to make the exact counter point … All this was confusing to me. (PII 3, reflection paper #1)

Simultaneously, these participants articulated their perceptions of the implications that these philosophical and NOS ideas had for teaching school science. Their perceptions were generally not different from those of the Methods group students. The POS group participants were still preoccupied with issues related to *whether* and *how* it was possible to teach secondary students about the specific NOS ideas they have just 'learned':

> After these first articles, and after immediately being bathed in conflicts, teaching teenagers philosophy and theories of science seems quite arduous. From a teaching perspective, I would embrace teaching my students the Scientific Method. I would much rather impart that as a method to students as I engage them in doing experiments … than to expose them to the idea that there might not be any one method for reaching scientific knowledge. (PII 4, reflection paper #2)

> Both induction and deduction are important to scientists, but the issue that I thought was the most important was whether or not it is good to tell students that induction is not always the way that scientists make scientific discoveries or prove their theories. Should teachers be honest with students and tell them that induction is not the only means for doing science? … I believe that for the classroom induction is a better philosophy to follow because it lays an organized foundation for the students to establish their scientific beliefs on. Deduction is extremely useful in the 'real world' of science, but for the classroom it would lead to too much confusion. (PI 1, reflection paper #1)

However, starting with the third reflection paper, a significant shift was evident in the thinking of the majority (70%) of the 10 POS group participants. These preservice teachers went one crucial step further than their Methods group counterparts and started to contemplate changes in their future teaching practices, including discourse, behaviours, 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 quote:

> 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 … 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 naive 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. (PI 4, reflection paper #3)

Rather than focusing on what ideas about NOS 'are safe or can be handled by high school students' (PII 5, reflection paper #2), many POS group participants started employing their newly acquired understandings about NOS — with which they now expressed greater comfort — to reflect on their own science learning careers:

> 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. (PI 1, reflection paper #4)

Instead of thinking of NOS concepts merely as new content to be covered in their future classrooms, these participants now employed their rather sophisticated NOS understandings as a tool for critical reflection, and as means of empowerment when thinking about their own teaching:

> My own understanding of the nature of science will surely come across by the way I say things … It is not mainly about teaching my own students these abstract philosophical concepts. It is about using tentative language in my own teaching when appropriate. I should not present science as infallible, nor downplay the importance of scientific knowledge … It might be relatively easy to bear in mind that my knowledge is tentative. However, when I speak I doubt my language sounds tentative. I am inclined to use things like the ideal gas law or Newton's Laws as 'matters of fact', even though I know they are at best approximately true. It is much simpler to treat established scientific knowledge as fact. I know better now and I have to keep reminding myself when I teach that I should avoid these pitfalls of getting across a grossly inaccurate picture of what science is. (PI 2, reflection paper #4)

The observed shift in the thinking of the majority of the POS group participants is (in a rather broad sense) consistent with a progression across the three domains of knowledge articulated by Habermas (1971); that is, from the *technical*, to the *practical*, and, finally, to the *emancipatory*. As these participants struggled with and internalized more informed and coherent views of NOS, their focus shifted from a preoccupation with discerning the 'accurate' meanings of the target philosophical ideas and how their own conceptions fare in comparison, to a concern with whether and how their newly acquired understandings could be translated into actual instructional outcomes in their future classrooms. In the latter part of the POS course, these concerns were shifted inwards and participants' NOS understandings now served as a lens to reflect on their science learning experiences and contemplate ways in which these understandings would allow them to escape the traditional molds in which science teaching and learning are often cast. In a sense, participants' NOS understandings now served an emancipatory role, a means to help them conceive of teaching behaviors that are different — in both subtle and palpable ways — from the realm of possibilities garnered from their own science learning experiences.

Instructional planning related to NOS

From the standpoint of impacting classroom teaching practices, the presented results are probably the most interesting and significant ones in the present study. Consistent with previous research findings (for example, Abd-El-Khalick et al. 1998, Bell et al. 2000, Lederman et al. 2001), the translation of participant preservice teachers' acquired NOS understandings — following NOS instruction in the context of science-methods courses — into instructional planning related to NOS was minimal. The lesson plans of only four of the 28 cohort I participants (14%) and four of the 18 cohort II participants (22%) in the Methods group, who received explicit reflective NOS instruction in Science Methods I, included explicit instances of planning to teach about NOS. In the case of both cohorts, one of these participants 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)' (MI 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' (MI 1, lesson plan #1). Four of these eight participants planned to teach about the distinction between observation and inference, and the empirical and tentative NOS. Others addressed the explanatory and predictive nature of scientific models and the process of validating such models. One 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 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' (MI 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 differences between observation and inference, and realize the tentative nature of their stories in light of 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, about 40% of the Methods group participants in both cohorts 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 on these opportunities to plan to teach their students something about the nature of generating and validating scientific claims.

By comparison, two of the four cohort I participants and four of the six cohort II participants in the POS group 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 cohort I 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 the tentativeness of scientific theories and the role of reinterpreting evidence in theory change. Of the cohort II POS group, two students aimed to address the nature of scientific models by incorporating black-box activities and historical vignettes in a lesson on the development of atomic models. Another student targeted the inferential and tentative nature of scientific claims in the context of a lesson on DNA fingerprinting. The fourth cohort II POS group participant planned to teach his students about the nature of theory testing by exploring the role of indirect evidence in validating relativity theory.

Even though the remaining four POS group participants did not explicitly plan to teach about NOS, a noteworthy aspect of the lessons they planned during the latter half of the 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, three of these 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 earlier, 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 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 already noted, many of these participants included science process skills objectives in their lesson plans but none capitalized on these instructional episodes to teach something about NOS.

Discussion and implications

The present results are significant in, at least, two major respects. First, compared with (the mostly limited) NOS instruction undertaken within the context of science methods courses (for example, Abd-El-Khalick et al. 1998, Akerson et al. 2000; Bell et al. 2000), the investigated POS course helped participant preservice teachers develop deeper, more coherent understandings of NOS. Second, relative to the Methods group participants, substantially more POS group participants translated their NOS understandings into explicitly planned instructional sequences. Even though these results were consistent with both participant cohorts, the results should, nonetheless, be viewed with caution. First, the number of participants in the POS group was relatively small and these participants were self-selected. The fact that these participants elected to enrol in the POS course reflects some initial interest on their part in issues related to NOS. It is not clear whether such interest developed as a result of these participants' exposure to NOS instruction in Science Methods I or as a result of some other factor(s). Second, the researcher was the instructor for the Methods and POS courses. Thus, despite measures undertaken to ensure the validity of analysing the data (namely, having another science educator conduct a blind round of data analysis), it would be very difficult to disregard the effect of the researcher having lived with the participants in each cohort for about nine months on the inferences presently reported. The reader is invited to take a critical stance in this regard. Third, the investigated POS course was not representative of 'typical' POS courses. While such courses have disciplinary subject matter as their primary focus, the investigated POS course was specifically designed to address the needs of science educators; that is, influence their views of NOS and encourage them to explore the implications that these views have for pre-college science teaching and learning. What is more, participants joined the POS course after having been explicitly sensitized to several NOS aspects in Science Methods I. Abd-El-Khalick and Lederman (2000b) argued that such sensitization is essential to helping science teachers derive more 'lessons' about NOS from their experiences with history and philosophy of science courses. Thus, the present results should be viewed as tentative. Also, the results cannot be generalized to other POS courses. However, these results provide some empirical support to the intuitive assumption that coursework in POS can substantially contribute to helping science teachers address NOS instructionally, which is a highly desired goal for current reform efforts in science education (AAAS 1990, NRC 1996).

Previous research has indicated that the translation of science teachers' NOS understandings into instructional practice is limited and mediated by a host of constraining factors (Abd-El-Khalick et al. 1998). These factors include pressure to cover content (Duschl and Wright 1989, Hodson 1993), classroom management and organizational principles (Hodson 1993, Lantz and Kass 1987, Lederman 1995), concerns for student abilities and motivation (Brickhouse and Bodner 1992, Duschl and Wright 1989, Lederman 1995), institutional constraints (Brickhouse and Bodner 1992), and teaching experience (Brickhouse and Bodner 1992, Lederman 1995). These empirical results, and justifiably so, have shifted the focus of research and development efforts that aim to help science teachers address NOS instructionally; these efforts now seem to be focused on providing teachers with support to cope with the identified constraining institutional and situational factors (for example, Lederman et al. 2001). While these latter efforts are surely worthwhile and necessary, they are *not* sufficient; they seem to have pushed attempts to enhance science teachers' NOS understandings to the background with the implicit assumption that such understandings could be taken for granted. However, our critical examination of the literature indicated that the attempts undertaken to enhance science teachers' NOS views have only met with little success (Abd-El-Khalick & Lederman 2000a).

It is my view that in research related to helping science teachers address NOS instructionally, teachers' NOS understandings *remain* a confounding variable. Indeed, in much of the earlier cited research it was difficult to ascertain whether the constraints reported were 'actual' or 'perceived'. In our own research (for example, Abd-El-Khalick et al. 1998) we actually qualified our results by noting that some of the constraining factors that were identified by our participants could also have been 'perceived' constraints. In several of the aforementioned studies, participant teachers' NOS views were assessed and/or participants received some NOS instruction. Next, participants' instructional practices were documented to assess whether their NOS views translated into classroom teaching. In some cases, participants were then confronted with the results and asked to explain why they 'failed' to address NOS instructionally. It is reasonable to assume that when faced with such discrepancy — that is, not having addressed NOS instructionally despite having some level of NOS understanding — participant teachers resorted to identifying a host of factors to justify this 'seeming' failure. However, it might as well have been the case that participants' understandings of NOS played a crucial role in determining whether they addressed NOS in their instruction.

This latter inference is supported by what is probably the most significant finding of the present study. We have seen that as participants in the POS course developed more thorough and coherent understandings of NOS, they moved beyond the customary discourse of our previous participants (for example, Abd-El-Khalick et al. 1998, Lederman et al. 2001) and participants in the Methods group; a discourse that primarily focused on whether it was possible to teach specific NOS ideas to school students. By comparison, after having developed some level of competency and comfort with important NOS issues, the discourse of the POS group participants shifted from a 'blame game' toward critical (and even emancipatory) self-reflection; these participants started contemplating changes they need to bring about in their own teaching behaviour and discourse to achieve consistency with their newly acquired NOS understandings. What is more, not only did more POS group participants plan to address NOS instructionally, their plans reflected the genesis of a NOS pedagogical content knowledge. This was reflected in their use of specific and accurate examples from history and practice of science in their reflection papers, discourse about NOS, and plans to address NOS instructionally. Of course, the *crucial* question of whether the POS group participants' NOS views and plans will translate into actual classroom practice remains to be answered. This question will be pursued after these students assume teaching positions.

There is an ever-widening consensus among educators, education organizations, and reform documents (for example, Abd-El-Khalick and BouJaoude 1997, Grossman et al. 1989, NRC 1996, 2000, National Commission on Mathematics and Science Teaching for the 21st Century 2000, Shulman 1986, 1987) that deep conceptual understanding of subject matter is a necessary and crucial component of teachers' knowledge and professional base for effective teaching. This should not be different in the case of NOS, which is a central instructional outcome in current science education reform documents (AAAS 1990, NRC 1996). Achieving deep understandings of NOS is a challenging undertaking, which cannot be equated with convincing science teachers of the validity of a few generalizations about NOS, such as that scientific knowledge is tentative or socially and culturally embedded. Achieving the desired level of understanding entails grappling and coming to terms with a sort of critical or committed relativistic (as compared with naive relativistic) epistemology, in which knowledge is constructed through social, collaborative inquiries that are fueled by creativity and constrained by empirical observations. Developing a deep understanding of NOS — the sort of understanding that might get science teachers to view NOS as an organizing theme for their own thinking and teaching practices — entails a shift from viewing issues related to knowledge generation dichotomously or as a matter of kind (e.g. true/false, right/wrong, proven/not-proven, subjective/objective) to viewing them as a matter of degree (e.g. valid/invalid, less subjective/more subjective). All this should be internalized while simultaneously realizing that while scientists do not have access to absolute truth about natural phenomena, adjudications between scientific claims (e.g. claim A is more valid than claim B) are still possible.

The present study provides *some* evidence indicating that a relatively sophisticated level of understanding of NOS could be achieved and that coursework in POS might put science teachers on the track of achieving such an understanding. At least, this study indicates that if we want teachers to address NOS instructionally, our efforts to help them develop the necessary understandings need to go beyond a few hours of NOS-related instruction in a science-methods course. Naturally, history and philosophy of science, which are the 'stuff' of NOS, are primary candidates for enriching the development of science teachers in the area of NOS (see Matthews 1994). However, there are two concerns in this regard. First, it cannot be assumed that coursework in history and philosophy of science will automatically result in substantially improved NOS understandings on the part of science teachers. Indeed, empirical research has indicated that history of science courses that did not include an explicit agenda coupled with explicit instruction with regards to NOS were not effective in impacting science teachers' views (Abd-El-Khalick and Lederman 2000b). Second, the agendas of science teacher education programmes are already extensive, and more pressure is put on such programmes to 'produce' teachers in even shorter periods of time in light of severe shortage of qualified science teachers (Urban Teacher Collaborative 2000). Thus, it is rather impractical to add a substantial requirement of history and philosophy of science coursework to these programs.

A reasonable approach to tackle this issue could take the form of a collaborative effort among historians, philosophers, and sociologists of science, and science educators to develop integrated courses that specifically address the needs of science teachers. For instance, such a course or course-sequence could be organized around critical episodes in history of science. The AAAS (1990) identifies 10 such critical episodes that are deemed central to the development and understanding of Western science (e.g. the shift from a geocentric to a heliocentric model of the solar system, the development of evolutionary theory). Case studies of these episodes could be used as vehicles to engage science teachers with some central issues in philosophy and sociology of science, while at the same time providing them with a holistic sense of the workings of science and the development of some central scientific theories. The development of these courses could surely benefit from a long-standing line of research on teaching and learning about NOS, which spans the past 40 years. It is understandable that this is not an easy undertaking, but I believe that it would prove worthwhile and fruitful. Finally, it should be noted that while the courses envisioned here resonate with the sort of courses on public understanding of science developed at Harvard in the 1940s and 1950s (Conant 1947, 1957), the presently envisioned courses are nonetheless substantially different in that they will be centred around the needs of science teachers and the aim of helping them, and hopefully their future students, develop informed views of NOS.

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