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The Influence of History of Science Courses on Students' Views of Nature of Science

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Abstract: This study (a) assessed the influence of three history of science (HOS) courses on college students' and preservice science teachers' conceptions of nature of science (NOS), (b) examined whether participants who entered the investigated courses with a conceptual framework consistent with contemporary NOS views achieved more elaborate NOS understandings, and (c) explored the aspects of the participant HOS courses that rendered them more "effective" in influencing students' views. Participants were 166 undergraduate and graduate students and 15 preservice secondary science teachers. An open-ended questionnaire in conjunction with individual interviews, was used to assess participants' pre- and postinstruction NOS views. Almost all participants held inadequate views of several NOS aspects at the outset of the study. Very few and limited changes in participants' views were evident at the conclusion of the courses. Change was evident in the views of relatively more participants, especially preservice science teachers, who entered the HOS courses with frameworks that were somewhat consistent with current NOS views. Moreover, explicitly addressing certain NOS aspects rendered the HOS courses relatively more effective in enhancing participants' NOS views. The results of this study do not lend empirical support to the intuitively appealing assumption held by many science educators that coursework in HOS will necessarily enhance students' and preservice science teachers' NOS views. However, explicitly addressing specific NOS aspects might enhance the effectiveness of HOS courses in this regard. Moreover, the study suggests that exposing preservice science teachers to explicit NOS instruction in science methods courses prior to their enrollment in HOS courses might increase the likelihood that their NOS views will be changed or enriched as a result of their experiences with HOS. © 2000 John Wiley & Sons, Inc. J Res Sci Teach 37: 1057–1095, 2000

Introduction

The objective of helping students develop adequate understandings of nature of science (NOS) is "one of the most commonly stated objectives for science education" (Kimball, 1967–

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68, p. 110). This objective has been agreed upon by most scientists, science education organizations, and science educators for the past 85 years (Abd-El-Khalick, Bell, & Lederman, 1998), and has recently been reemphasized in major reform efforts in science education (American Association for the Advancement of Science [AAAS], 1990, 1993; Millar & Osborne, 1998; National Research Council [NRC], 1996).

The longevity of the objective of helping students develop adequate views of NOS has been surpassed only by the longevity of students' inability to delineate the meaning of the phrase "NOS," and to elucidate the associated characteristics of science (Abd-El-Khalick et al., 1998). Research has consistently shown that students' and teachers' views of NOS are not consistent with contemporary conceptions of the scientific endeavor (Duschl, 1990; Lederman, 1992). In the attempt to mitigate this state of affairs, research efforts have focused on helping science teachers develop "adequate" conceptions of NOS (for a comprehensive review of this literature, see Abd-El-Khalick & Lederman, 2000).

Generally speaking, researchers have used either an *implicit* or an *explicit* approach in their attempts to enhance teachers' NOS views. Researchers who adopted an explicit approach (e.g., Akindehin, 1988; Billeh & Hasan, 1975; Carey & Stauss, 1968; Jones, 1969) utilized elements from history and philosophy of science and/or instruction geared toward various aspects of NOS to improve science teachers' conceptions of the scientific endeavor. Researchers who adopted an implicit approach used science process–skills instruction and/or scientific inquiry activities (e.g., Barufaldi, Bethel, & Lamb, 1977; Riley, 1979) or manipulated certain aspects of the learning environment (e.g., Haukoos & Penick, 1983, 1985; Scharmann, 1990; Spears & Zollman, 1977) to achieve the same goal.

In this regard, it cannot be over-emphasized that the above distinction should not be taken to mean that implicit and explicit approaches differ in terms of "kind." That is, not every science process–skills instructional sequence or scientific inquiry activity is an implicit attempt to enhance learners' conceptions of NOS, nor is every instructional sequence in history of science (HOS) an explicit attempt to achieve that end. The basic difference between implicit and explicit approaches lies in the extent to which learners are helped to come to grips with the conceptual tools, in this case specific aspects of NOS, which would enable them to think about and reflect on the activities in which they are engaged (Abd-El-Khalick & Lederman, 2000).

Lederman (1992) noted that research concerned with improving science teachers' NOS conceptions was based on the assumption that teachers' conceptions directly transfer into their classroom practices. However, empirical studies that tested this assumption indicated that the relationship between teachers' NOS conceptions and their classroom practice was more complex than originally assumed (Lederman & Druger, 1985; Lederman & Zeidler, 1987). Several variables have been shown to mediate and constrain the translation of teachers' NOS conceptions into practice (Abd-El-Khalick et al., 1998; Brickhouse & Bodner, 1992; Hodson, 1993; Lantz & Kass, 1987; Lederman, 1999).

It is obvious that teachers cannot possibly teach what they do not understand. To be able to convey to their students adequate NOS conceptions, teachers should themselves possess informed conceptions of the scientific enterprise. However, research on the translation of teachers' conceptions into classroom practice indicates, and rightly so, that even though teachers' conceptions of NOS can be thought of as a *necessary* condition, these conceptions, nevertheless, should not be considered *sufficient* (Lederman, 1992). At least one implication for research related to NOS is apparent. Research efforts, it is argued, should "extend well beyond teachers' understandings of the nature of science, as the translation of these understandings into classroom practice is mediated by a complex set of situational variables" (Lederman, 1992, p. 351). Research efforts should, for instance, focus on factors, such as institutional support and curricular emphases, which might facilitate the translation of teachers' conceptions of NOS into actual instructional activities.

This latter recommendation, however, is itself based on the assumption that the necessary condition has been sufficiently met: That is, it is assumed that attempts to improve teachers' NOS views have been "successful" in promoting among teachers understandings that would enable them to convey adequate conceptions of NOS to their students. This assumption, nonetheless, is not supported by the empirical literature. In their comprehensive and critical review of this literature, Abd-El-Khalick and Lederman (2000) concluded that the aforementioned attempts were not successful in fostering among science teachers the desired understandings of NOS. Moreover, this review indicated that an explicit approach (which should not be confused with a didactic approach) that utilizes elements from history and philosophy of science might be more effective than an implicit approach in enhancing science teachers' NOS views.

This critical review, it should be noted, was undertaken from the standpoint that effective teaching requires more than basic knowledge of a target topic and mastery of general pedagogical principles: Such teaching requires pedagogical content knowledge (PCK) for the topic under consideration (Shulman, 1987; Wilson, Shulman, & Richert, 1987). To be able to effectively teach NOS to K-12 students, science teachers need to have more than a rudimentary or superficial knowledge and understanding of various NOS aspects. Teachers need to know a wide range of related examples, explanations, demonstrations, and historical episodes. They should be able to comfortably discourse about various NOS aspects, contextualize their NOS teaching with some examples or "stories" from HOS, 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 PCK.

A Role for HOS in Improving Teachers' Conceptions of NOS

In the absence of any systemic reform of science teaching, especially at the college level, it is highly likely that teacher candidates will continue to join teacher education programs with inadequate views of NOS (Stofflett & Stoddart, 1994). Science teacher education programs should continue their efforts to enhance prospective teachers' NOS views. However, there is a limit to what can be done within the context of teacher education programs given their already extensive and overly long agendas.

The relative ineffectiveness of the attempts undertaken to enhance science teachers' NOS views should not be surprising, given that the duration of the interventions were very short (Abd-El-Khalick & Lederman, 2000). The majority of these interventions were undertaken in the context of preservice science methods courses or inservice programs and typically lasted a few hours (e.g., Scharmann, 1990) or a few days (e.g., Akindehin, 1988). Given the multitude of objectives that such courses and programs often aim to achieve, it is difficult to imagine that more time can be allotted to dealing with NOS in these contexts. It is highly unlikely that science teachers' views of the scientific enterprise, views that have developed over the course of at least 16 years of precollege and college science, can be effectively changed, updated or elaborated during a few hours, days or weeks for that matter.

As such, the efforts to enhance prospective teachers' NOS views undertaken within science teacher education programs need to be augmented with relevant coursework in other disciplinary departments (Brush, 1969; Matthews, 1994). Intuitively, coursework in philosophy and history of science serve as primary candidates (see Brush, 1989; Matthews, 1994; O'Brien & Korth, 1991; Robinson, 1969; Scheffler, 1973). Indeed, during the past 70 years, science educators (e.g., Conant, 1947; Duschl, 1990; Haywood, 1927; Klopfer, 1969; Klopfer & Watson, 1957; Monk &

Osborne, 1997; Rutherford, 1964; Wandersee, 1992) have repeatedly argued that HOS can play a significant role in helping learners develop more adequate conceptions of the scientific enterprise.

However, despite the longevity of these arguments, and to the best of the researchers' knowledge, there is not *one* single empirical study in the science education literature that examined the influence of college level HOS courses on learners' NOS views. Recommendations for including HOS coursework in the preparation of science teachers are solely based on intuitive assumptions, anecdotal evidence, and virtually no supportive empirical literature. Science educators have mainly studied the influence of science teaching that incorporates HOS on learners' conceptions (Russell, 1981) and inferred a potentially useful role for HOS coursework in improving prospective teachers' conceptions of NOS.

Some may argue, and understandably so, that what was stated above regarding the lack of empirical evidence to support the inclusion of HOS courses in the preparation of science teachers is not totally justified. After all, if incorporating HOS in science teaching was successful in enhancing learners' NOS conceptions, it may be plausible to infer that HOS can have a similarly positive influence on learners' views. However, a review of the efforts that aimed to assess the influence of incorporating HOS in science teaching on students' conceptions of NOS (Klopfer & Cooley, 1963; Solomon, Duveen, Scot, & McCarthy, 1992; Welch & Walberg, 1972; Yager & Wick, 1966) indicates that evidence concerning the effectiveness of this approach is, at best, inconclusive.

In this regard, interestingly enough, discussions about the effectiveness of incorporating HOS in science teaching by its originators and reviewers brings back to light the earlier discussion about implicit and explicit approaches to improving learners' NOS views. Klopfer (1969) noted that for this approach to be effective, "adequate time should be allowed for discussion so that the subtle understandings in the historical narrative may be fully developed" (p. 93). Similarly, Russell (1981), in a review of the attempts to incorporate HOS in science teaching, argued that "if we wish to use the history of science to influence students' understanding of science, we must... treat [historical] material in ways which illuminate particular characteristics of science" (p. 56). It seems that HOS itself may not suffice to improve learners' views of science. Aspects of NOS that are deemed important for students to understand need to be given explicit attention. These concerns about the use of HOS, however, are mainly related to instructional goals and practices. Nevertheless, on a more profound level, there seem to be some difficulties inherent to using HOS to enhance learners' conceptions of NOS.

The Historical Approach: Putting on a Different Kind of Thinking Cap

In his *The Essential Tension*, Kuhn (1977) described his first historical endeavor; an attempt to understand the origins of 17th century mechanics. Kuhn reasoned that he first needed to understand what Galileo and Newton's predecessors had known about the subject, which led him to examine Aristotle's writings on motion. Kuhn started by asking questions of Aristotelian texts. His questions being posed in a "Newtonian vocabulary, ... demanded answers in the same terms, and the answers then were clear .... the Aristotelians had known little of mechanics; much of what they had had to say about it was simply wrong" (p. xi). Kuhn, however, found this to be very perplexing. After all, Aristotle had been an astute observer, "his interpretations of phenomena had often been ... both penetrating and deep ... How could he have said about it [motion] so many apparently absurd things" (p. xi). One day, Kuhn (1977) continued, "I all at once perceived the connected rudiments of an *alternate* way of reading the texts with which I had been struggling [italics added]'' (p. xi). After this alternate way of reading was achieved, Kuhn noted, ''strained metaphors often became naturalistic reports, and much apparent absurdity vanished. I did not become an Aristotelian physicist as a result but I had to some extent learned to think like one'' (p. xii).

This short narrative serves at once to outline Kuhn's philosophical views about science and HOS, and to highlight the difficulty inherent in using HOS to acquire an understanding of NOS. Kuhn's (1970) ideas about paradigms are too well known to be reiterated here. Suffice it to say, for present purposes, that individuals view the world from within a certain paradigm or conceptual framework shared by their community. In a sense, those individuals live in a phenomenal world mediated by a shared language and comprehended from within an associated set of inter-subjective meanings (Hoyningen-Huene, 1993). What is more, Kuhn advanced that paradigms or phenomenal worlds are incommensurable (see also Feyerabend, 1993). That is, individuals with different paradigms live in different phenomenal worlds even though they share the same experiential world. Individuals can view another community's phenomenal world and attempt to comprehend it only from within the conceptual entities that make up their own (Hoyningen-Huene, 1993).

Thus, when Kuhn asked questions of Aristotelian writings on motion, he did so from within a Newtonian framework. This latter framework was an integral part of a cosmology and scientific web of ideas that were profoundly different from the Aristotelians'. In a similar fashion, when learners are faced with historical narratives, they tend to ask questions of those narratives from within certain conceptual frameworks, which are mainly what the learners happen to know about the target subject now. As far as prospective science teachers are concerned, their frameworks of science have developed over years of high school and college science and, as noted earlier, these frameworks are mainly incongruent with current conceptions of NOS. HOS is viewed from within these conceptual frameworks. Thus, in the same manner that Kuhn had found Aristotelian writings to be simply wrong and much of what the Aristotelians had had to say to be absurd, learners often dismiss historical scientific notions as wrong ways of explaining the natural world. HOS is not viewed or interpreted as being a repository for the active attempts of earlier scientists to understand the natural world from within certain sets of culturally and cosmologically embedded conceptual tools. HOS is rather read from within the spectacles of present scientific ideas and indiscriminately judged from the viewpoint of present day knowledge. As such, the subtleties of the historical narrative are often lost and ''lessons'' about NOS are disregarded.

However, Kuhn's (1970) incommensurability thesis has been criticized by many philosophers of science (e.g., Lakatos, 1978; Popper, 1970, 1994). Had his thesis been ''true,'' it would have been virtually impossible for Kuhn himself to achieve what he had claimed. For even though Kuhn did not become an Aristotelian physicist, he did, nevertheless, learn to think like one. Kuhn, in a sense, learned the Aristotelian paradigm and was almost able to live in the Aristotelian phenomenal world. But achieving this understanding of the Aristotelian paradigm was possible only through learning an alternate way of reading historical materials through ''recapturing out-of-date ways of reading out-of-date texts'' (Kuhn, 1977, p. xiii). This shift in thinking was described by Butterfield (1965) as ''putting on a different kind of thinking cap'' (p. 1).

So, even if there is no willingness to accept Kuhn's incommensurability thesis, there should be a recognition that a genuine effort and extended commitment should be undertaken on the part of learners to achieve the kind of conceptual shift necessary to make the historical approach useful for learning *about* science. Kuhn's arguments find support in the writings of Brush (1969, 1979) who has put forth similar ideas.

The need to ‘‘put on a different kind of thinking cap,’’ as such, might seriously compromise the effectiveness of the historical approach in conveying to learners more adequate conceptions of NOS. It might be difficult for prospective science teachers enrolled in HOS courses to replace their ‘‘thinking cap,’’ one that has developed throughout their science-learning careers, with an alternate ‘‘cap.’’ Adopting an alternate way of ‘‘reading’’ historical material is all the more less likely if those student teachers are expected to achieve this conceptual shift on their own given that they will be exposed, at best, to few HOS courses. One possible way to ameliorate this obstacle is to provide prospective teachers with a conceptual framework consistent with current conceptions of NOS prior to their enrollment in HOS courses. Such a framework can be developed, and indeed has been developed with some success, within science methods courses (e.g., Abd-El-Khalick et al., 1998; Akerson, Abd-El-Khalick, & Lederman, 2000). This framework would serve as an alternate way of reading the historical narrative, thus focusing prospective teachers’ examination of that narrative on aspects of NOS that are consistent with a contemporary view of the scientific endeavor. HOS courses can thus serve to elaborate and deepen student teachers’ understandings of NOS and to enrich their framework with examples, metaphors, and stories related to the various NOS aspects. This enriched understanding may in turn impact those student teachers’ instructional practices related to NOS.

The purpose of the present study was to assess the influence of college-level HOS courses on students’ and prospective secondary science teachers’ conceptions of NOS. Specifically, three research questions guided this investigation:

1. Do HOS courses influence college students’ conceptions of NOS? If yes, in what ways?
2. Are students, including student teachers, who enter HOS courses with a conceptual framework consistent with current conceptions of the scientific enterprise more likely to achieve, if any, more adequate and enriched understandings of NOS?
3. To what extent, if any, do various HOS course aspects influence their effectiveness in influencing students’ conceptions of NOS? These aspects included (a) course objectives, (b) instructor priorities, such as the commitment to enhance learners’ NOS conceptions, (c) teaching approach, such as explicit attention to NOS or striving to help students develop alternate ways of reading HOS, and (d) classroom dynamics, such as large, lecture-oriented versus small, discussion-oriented courses. Before presenting the methodology of the present study, it should prove useful to elaborate on what the researchers mean by the phrase NOS.

NOS

The phrase ‘‘nature of science’’ typically refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992). Beyond these general characterizations, philosophers of science, historians of science, sociologists of science, scientists, and science educators are quick to disagree on a specific definition for NOS (Abd-El-Khalick et al., 1998; Losee, 1993). The use of the phrase ‘‘NOS’’ throughout this paper instead of the more stylistically appropriate ‘‘the NOS,’’ is intended to reflect the authors’ lack of belief in the existence of a singular NOS or agreement on what the phrase specifically means.

This lack of consensus, however, should not be disconcerting or surprising given the multifaceted and complex nature of the scientific endeavor. Like scientific knowledge, conceptions of NOS are dynamic and have changed throughout the development of science and systematic thinking about science (see Abd-El-Khalick & Lederman, 2000). Moreover, despite continuing disagreements about a specific definition for NOS, at a certain level of generality and within a certain period of time, there is a "shared wisdom" about NOS. For example, it should prove very difficult to reject the theory-laden nature of scientific observations, or to defend a deterministic/absolutist conception of NOS at our present times.

More importantly, for purposes of teaching and learning about NOS at the precollege level, we believe that at such a level of generality, some important aspects of NOS are virtually noncontroversial and also accessible to K-12 students. Among the characteristics of the scientific enterprise corresponding to this level of generality are that scientific knowledge is: (a) tentative (subject to change); (b) empirically-based (based on and/or derived from observations of the natural world); (c) subjective (theory-laden); (d) partially based on human inference, imagination, and creativity; and (e) socially and culturally embedded. Two additional important aspects are the distinction between observation and inference, and the functions of, and relationship between scientific theories and laws. It should be noted that these aspects of NOS, which were adopted and emphasized in the present study, have also been emphasized in recent reform documents in science education, such as *Science for All Americans* (AAAS, 1990) and *National Science Education Standards* (NRC, 1996).

The seven NOS aspects presently emphasized are necessarily interrelated in important ways and embedded within a larger web of ideas about the nature of the scientific endeavor and the ways in which scientific knowledge is generated and validated. The semantic map shown in Figure 1 presents an overview of this interrelatedness and embeddedness, and is intended to contextualize our discussions of participants' views of NOS. The map is best read starting with the term "science" in the very center and then going outwards along the various branches. It cannot be overemphasized, however, that this map is not intended to advance a final or complete representation of what science is. It should prove very difficult to capture the multifaceted and complex NOS, even at a more or less agreed on level of generality, in a two-dimensional representation. Moreover, we make no claims as the exhaustiveness of the concepts and links depicted in the map. Readers will surely be able to add more relevant concepts and/or generate more valid links, or simply come up with an entirely different, but equally valid map of their own.

Method

The present study was interpretive in nature (LeCompte & Preissle, 1993). Data collection was continuous and spanned the entire term during which participant students and student teachers were enrolled in the investigated HOS courses. Figure 2 presents an overview of the study's participant students and courses, timeline, procedure, instruments, and data sources.

Participants

Participants were 181 college students, 95 male (52%) and 86 female (48%). Their ages ranged from 19 to 45 years with a median of 23 years and an average of 24.5 years ($SD = 5.0$ years). At the time of the study, the participants were 1% sophomores, 13% juniors, 67% seniors, and 19% graduates. Most of the participants majored in one of the biological sciences (55%) or in general science (17%). Fifteen (9%) were preservice secondary science teachers. The remaining participants (19%) had other majors.

Participants comprised two groups. The first included all 166 undergraduate and graduate students enrolled in three HOS courses offered during Fall term in a mid-sized state university on

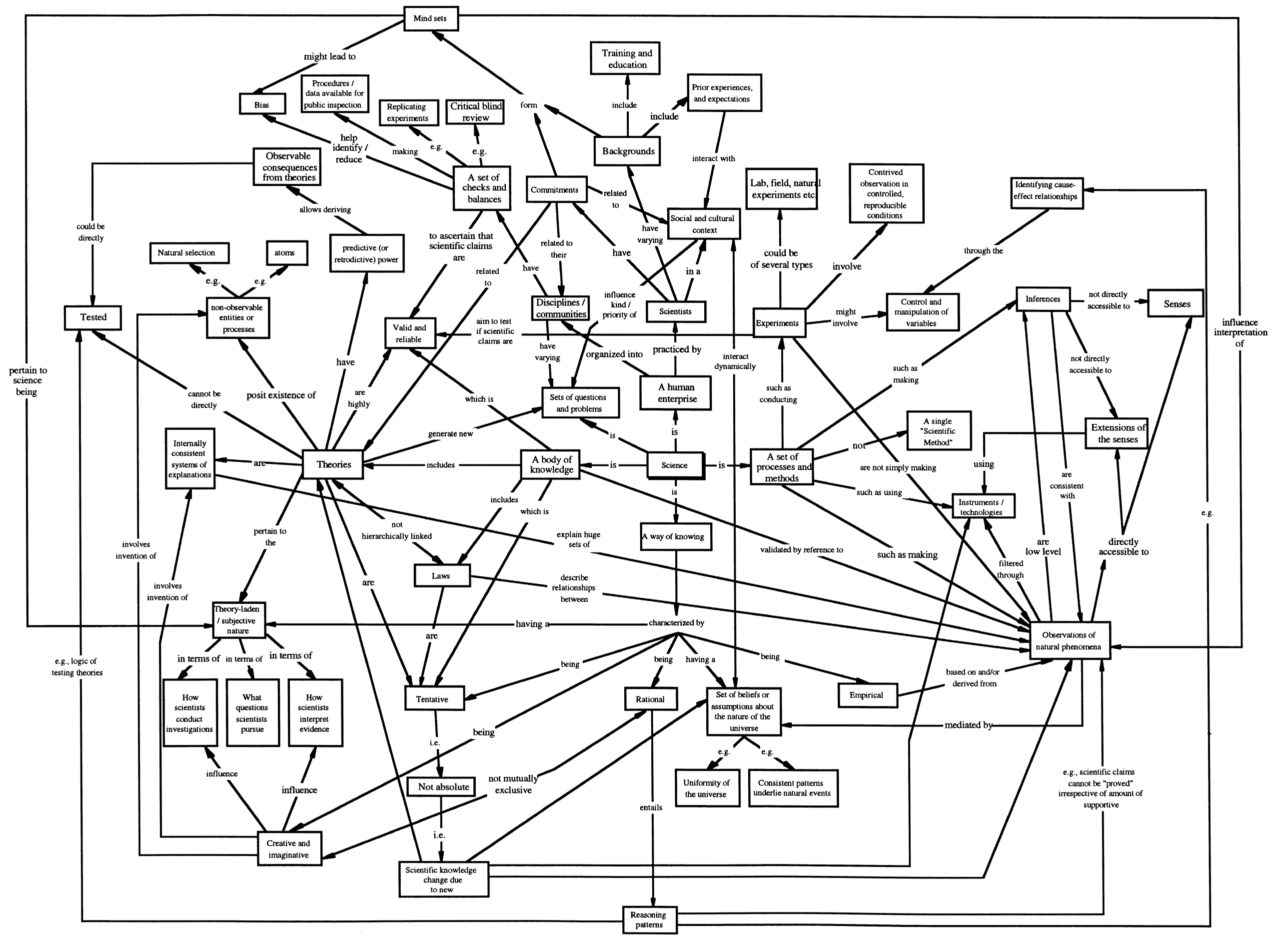

Figure 1. An overview of the interrelatedness and embeddedness of the aspects of NOS emphasized in this study within a broader conception of science and the generation and validation of scientific knowledge.

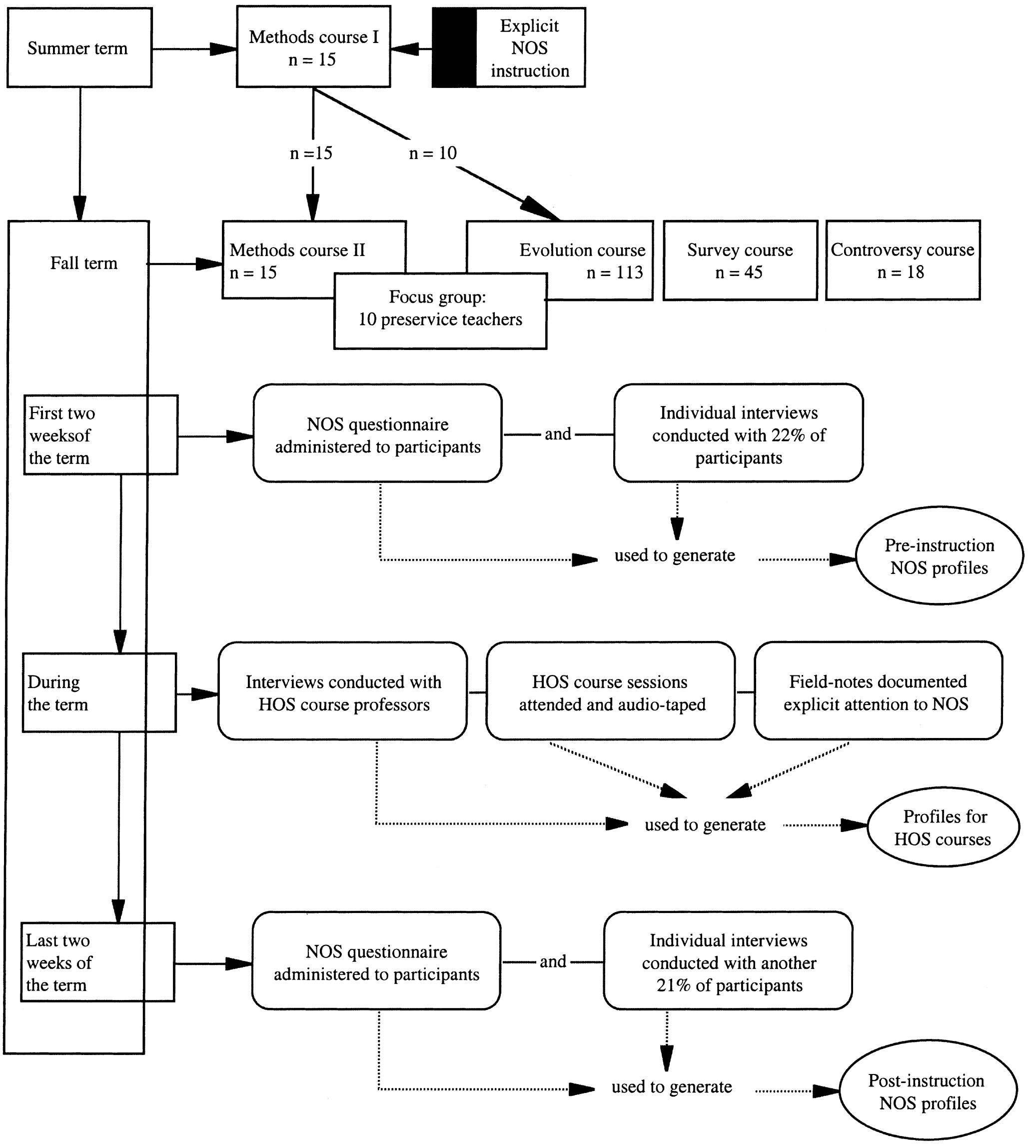

Figure 2. An overview of the study's participant students and courses, timeline, procedure, instruments, and data sources.

the West Coast. The second group consisted of all 15 preservice secondary science teachers, eight male and seven female, enrolled in a fifth-year Master of Arts in Teaching (MAT) program at the same university. At the time of the study, all preservice teachers were enrolled in a science methods/practicum course. A focus group consisted of the 10 preservice teachers enrolled in a participant HOS course (see Figure 2).

An overwhelming majority of participants (85%) had no prior instruction in history and philosophy of science. Of 25 and 17 students who indicated having completed coursework in HOS and philosophy of science prior to their participation in this study, 17 (68%) and 13 (76%) noted that they had completed one such course, respectively. Only seven participants (4%) completed coursework in both history and philosophy of science. As far as science background was concerned, participants completed an average of 67 undergraduate credit hours ($SD = 36.5$) in the various disciplines. Most of these credits (90%) were in the biological ($M = 33$ credit hours, $SD = 24.4$) and physical ($M = 27.2$ credit hours, $SD = 16.4$) sciences. Participant preservice teachers had earned Bachelor of Science (BS) degrees prior to joining the MAT program. It is noteworthy that graduate participants did not differ much in their science background from the undergraduates since most of them (about 73%) had just begun their graduate studies at the time of the study. Similarly, with the exception of two graduate students who majored in HOS, graduate students did not differ from undergraduates in their history and philosophy of science backgrounds.

Context of the Study: Participant Courses

Students could enroll in the participant HOS courses for undergraduate or graduate credit. Both undergraduate and graduate students attend the same class meetings and are required to complete the same assignments. Graduate students, however, are required to demonstrate a more in-depth understanding of the course materials.

The first course, entitled ‘‘Studies in Scientific Controversy’’ (the ‘‘Controversy’’ course), focuses on accounts of controversial scientific discoveries. Using case studies from the 17th through 20th centuries, the course aims to highlight the rational, psychological, and social characteristics that have typified the meaning and methods of the natural sciences. The second course, ‘‘History of Science’’ (the ‘‘Survey’’ course), is a survey course that focuses on the interaction of scientific ideas with their social and cultural contexts. The course covers the period from ancient civilization to the post-Roman era. The third course, entitled ‘‘Evolution and Modern Biology’’ (the ‘‘Evolution’’ course), focuses on the origin and development of Darwin’s theory of evolution. The course also explores the reception and history of evolution theory from its inception to the present.

The participant HOS courses had different objectives and were taught by three HOS professors. The courses, thus, were likely to reflect a range of historical and teaching approaches. Also, by virtue of student enrollment, the courses exhibited different classroom dynamics. The Controversy course was a small-size (18 students) discussion-oriented course . The Survey and Evolution courses were mid-sized (45 students) and large (113 students) courses, respectively. The latter courses were both lecture-oriented. Two participants were enrolled in both the Survey and Controversy courses, and one participant was enrolled in both the Survey and Evolution courses. It should be noted that participants’ biographical profiles in all three HOS courses as well as their HOS, philosophy of science, and science backgrounds were comparable and did not differ in any appreciable respect.

The Science Methods/Practicum II course (the ‘‘Methods’’ course), in which participant preservice teachers were enrolled at the time of the study, focused on classroom management, instructional planning, traditional and alternative assessments, and models of teaching. It is noteworthy that the participant preservice teachers’ history and philosophy of science backgrounds were similar to those of other students enrolled in the HOS courses. The only appreciable difference was the relatively larger number of undergraduate science credits completed by the preservice teachers. This difference was expected given that all participant preservice teachers had already earned BS degrees. Additionally, preservice teachers enrolled in the Evolution and Methods courses ($n = 10$) were comparable in almost all respects to those enrolled in the Methods course only ($n = 5$).

The Methods course was the second in a sequence that started in the Summer term when the student teachers joined the MAT program (see Figure 2). The Summer course (Science Methods/ Practicum I) focused, among other things, on NOS. Over the course of eight instructional hours, participant student teachers received explicit instruction about the seven aspects of NOS emphasized in the present study. Preservice teachers directly experienced or discussed 15 different NOS activities. Detailed descriptions of these activities can be found elsewhere (Lederman & Abd-El-Khalick, 1998). In general, some of these NOS activities were content-embedded while others were generic. An example of a content-embedded activity was the fossil activity in which preservice teachers were provided with fossil fragments and asked to draw detailed representations of these fragments. Student teachers were then asked to infer and draw the remainder of the fossilized organism and make inferences about their organisms' habitats and nutrition. Following presentations of the inferred "organisms" to the rest of the class, preservice teachers were engaged in a discussion that related this activity to the scientific activities of paleobiologists, tentativeness of science, the use of creativity in the development of scientific knowledge, the theory-laden nature of scientific observations and inferences, and the necessity of empirical evidence. The generic activities were mostly of the "black-box" variety. In such activities, student teachers were shown a particular "phenomenon" and asked to infer how it works. They were then asked to design and construct models that mimic the behavior of the phenomenon without ever "seeing" what was inside the "black-box." Ensuing discussions focused on the distinction between observation and inference, the role of models and theoretical constructs in science, tentativeness of science, and the role of creativity in devising scientific explanations.

HOS courses: An abbreviated profile. The HOS courses (all are 3 credit-hour courses) spanned 10 weeks. In the Evolution course, students met for three 50-minute sessions each week. Students in both the Survey and Controversy courses met for two 80-minute sessions each week. All three HOS professors indicated that their courses aim to convey to students some understandings about the "process" of science. Only the Evolution course professor voiced an explicit commitment to helping students develop adequate conceptions of NOS. He believed that an understanding of NOS is a central component of scientific literacy and has direct relevance to students' everyday lives. Moreover, the Evolution course professor explicated his aim to teach about specific aspects of NOS.

The priority given to the historical dimension of the course materials was apparent in all three courses, but was most pronounced in the Controversy course. Moreover, a "historically oriented" teaching approach was most pronounced in the Evolution course. The Evolution course professor indicated that he aimed to help students examine the course materials from a perspective that was radically different from their own:

> What I am trying very hard to do is to get students to pull themselves out of the contemporary setting. To forget about their own assumptions, to forget what they think about evolution and to put themselves into a different context and try to see the world through the eyes of someone else. And the purpose of doing that is when they return to their own world they start to think about their assumptions, their epistemological assumptions, [and] their ontological assumptions. (Evolution course professor, interview)

This attempt was clearly manifest in the various Evolution course activities and assessment strategies. For instance, on the midterm, students were asked to evaluate Darwin's *The Origin of Species* as if they were living in the 19th century:

> Think of yourself as being a university student in 1860, that is the year right after the *Origin* was published . . . What I want you to do is to write an essay, as you would have written an essay in the 19th century, 1860, to evaluate the *Origin*. You don't know anything about DNA, you don't know anything about population genetics, you just know Linneaus, Buffon, Paley, and Cuvier. (Evolution course, lecture transcripts, 10/17/1997)

In general, all three courses did not utilize an explicit approach to teaching about NOS. The absence of an explicit approach was pronounced in the Controversy course. The Controversy course professor explored several NOS aspects, particularly the nature of scientific experiments and the psychological and sociological dimensions of science. The professor, however, articulated few explicit generalizations about the nature of scientific knowledge and practice. The Survey course professor explicitly addressed one aspect of NOS, namely the social and cultural embeddedness of science.

The Evolution course professor made relatively more explicit, but brief, references to a few aspects of NOS. Notably, the Evolution course professor also presented two explicit and relatively extended (15–20 min) discussions about NOS and scientific theories. The tentativeness of scientific theories and their explanatory function were particularly emphasized. The Evolution course professor also discussed the nature of theory testing, and the considerations associated with the use of the term ''prove.'' For instance, in his discussion of students' responses to the midterm examination, he noted:

> Some of you talked about Darwin not having enough proof for his theory. Well, this is very tricky because . . . we use the word ''proving'' and ''proof'' to mean evidence or validation. But generally we use the word proof in a more robust way as guaranteeing certainty. You don't prove scientific theories. You cannot run a test to prove a theory. Scientific theories are never proven in that sense, we provide evidence, theories are stronger or weaker, more valid or less valid. But we don't prove a scientific theory the way we prove a theorem say in geometry. (Evolution course, lecture transcripts, 10/27/1997)

The Evolution course professor also emphasized the role of scientific theories in guiding research:

> Evolution raised a number of interesting questions. That's one thing that theories do. Theories explain and guide research. If you take evolution seriously . . . it immediately becomes important to understand the origin of variation, and this turned out to be a very fruitful topic of investigation. Similarly, genetics becomes very interesting . . . This is a theory that opened up new areas of research. (Evolution course, lecture transcripts, 11/21/1997)

The Evolution course professor emphasized the role of sociological factors in science. He noted that science is a human enterprise and that scientists are a self-conscious group. As such, in addition to logical considerations, professional and sociological factors as well as practical concerns, play an important role in the generation and validation of scientific knowledge. Moreover, he emphasized the social and cultural embeddedness of science noting that scientists are part of a larger societal and cultural context and are indoctrinated into that context's assumptions and concerns.

Table 1
Response rates to NOS questionnaire

Completed Questionnaires	Survey ($N=45$)		Evolution ($N=113$)		Controversy ($N=18$)		Method ($N=15$)	
	n	*P*	*n*	*P*	*n*	*P*	*n*	*P*
Pre-instruction	45	100	104	92	18	100	15	100
Postinstruction	44	98	100	88	15	83	15	100
Both	44	98	95	84	15	83	15	100

Note. N refers to the total number of students enrolled in the specified course whereas n refers to the number of students who completed the NOS questionnaire. P = percentage.

Procedure

Several data sources were used to answer the questions of interest. An open-ended questionnaire in conjunction with follow-up, semi-structured interviews was used to assess participants' conceptions of NOS. Moreover, a semi-structured interview with the HOS course instructors in conjunction with course syllabi and classroom observations, were used to generate in-depth profiles of the courses (see Figure 2).

All participants in their respective courses were administered an open-ended questionnaire intended to assess their conceptions of NOS during the first and last weeks of Fall term. Table 1 presents the number and percentage of participants in each course who completed the pre-instruction questionnaire, the postinstruction questionnaire, and those who completed both questionnaires. It should be noted that all preservice teachers and practically all participants in the Survey course (98%) completed both questionnaires. The response rates for the Evolution course (84%) and the Controversy course (83%) were relatively high. Moreover, in both the Evolution and Controversy courses nonrespondents did not differ in any systematic manner from respondents to the open-ended questionnaire.

The questionnaire was used in conjunction with follow-up semi-structured interviews, which aimed to clarify participants' responses to the questionnaire and generate in-depth profiles of their views. A random sample of 45% of the participants was generated such that the number of participants chosen from each course was proportional to the total number of students enrolled in that course. Participants in this sample were randomly split into two sub-samples. Students in the first sub-sample were interviewed within the first two weeks and those in the second sub-sample during the last two weeks of the term. In addition, half of the participant preservice teachers were randomly chosen and interviewed at the beginning of the term. The remaining preservice teachers were interviewed during the last week of the term. A total of 78 (43%) participants were interviewed. The interviews typically lasted between 30 min and 1 hr. All interviews were audio-taped and transcribed for analysis.

Additionally, the HOS professors were interviewed to generate in-depth profiles of their respective courses. The interview aimed to identify the course objectives, instructor priorities, historical approach used, and the instructor's views on the relationships between HOS, science, and science teaching. Interviews were audio-taped and transcribed for analysis. The primary researcher sat through the HOS courses, audio-taped all course sessions, and kept detailed field notes. These notes primarily focused on documenting instances where aspects of NOS were emphasized in the observed lectures and/or discussions. Classroom segments corresponding to these latter instances were transcribed for analysis.

Instruments

Using an open-ended questionnaire in conjunction with follow-up interviews to assess participants' conceptions of NOS was undertaken with the intent of avoiding the problems inherent to the use of standardized, forced-choice (e.g., true/false, agree/disagree) instruments that have been traditionally employed to assess learners' views of the scientific enterprise (see Lederman, Wade, & Bell, 1998). The use of open-ended questions allows respondents to express their own views on issues related to NOS, thus alleviating concerns related to imposing on respondents a particular view of the scientific enterprise. Moreover, by asking respondents to elaborate and/or justify their answers, open-ended questions allow researchers to assess not only respondents' positions on issues related to NOS, but the respondents' reasons for adopting those positions as well.

NOS questionnaire. The questionnaire consisted of nine open-ended items that aimed to assess the previously delineated NOS aspects (see Appendix A). An initial set of nine items was adapted from questionnaires developed by Lederman and O'Malley (1990) and Abd-El-Khalick et al. (1998), in addition to items developed by the primary researcher. Next, a panel of experts examined these items to establish their face validity. This panel consisted of five university professors: three science educators; a historian of science; and a scientist. The nine items were modified according to the panel's comments and suggestions for improvement.

Student semi-structured interviews. Given the present study's concern with the meanings that participants ascribed to the target aspects of NOS, it was imperative to avoid misinterpreting participants' responses to the open-ended questionnaire. As such, individual semi-structured interviews were used to establish the validity of the questionnaire by insuring that the researchers' interpretations corresponded to those of participants (Lederman, 1992; Lederman & O'Malley, 1990). During the interviews, which were conducted by the first author, participants were provided their pre- or postinstruction questionnaires and asked to explain and justify their responses. Follow-up questions were used to clarify participants' responses and further probe their lines of reasoning on issues raised in the questionnaire.

Each administration of the questionnaire was followed by semi-structured interviews with students in the representative random sub-samples and the focus group. Feasibility was the only reason for interviewing a representative sample rather than all the participants. Given the duration of the study, which was set by the 10-week span of the participant courses, it was not possible to interview all participants at the beginning and conclusion of the study and still consider the interviews to be pre- and postintsruction assessments.

Initially, follow-up questions were not planned. However, following the first few pre-instruction interviews a common set of follow-up, clarification, and probing questions "emerged" and took form. These questions were asked of interviewees either as individual questions or "sets" of interrelated questions. Certain questions or sets of questions were asked following interviewees' explication of their responses to a certain item on NOS questionnaire. Alternatively, other questions or sets of questions were only asked when interviewees expressed certain ideas regarding NOS (see Abd-El-Khalick, 1998).

The same procedure and set of follow-up questions were used during postinstruction interviews, which followed the second administration of the questionnaire. Additionally, postinstruction interviews aimed to assess whether participants' views have changed. After explaining their responses to a certain item, interviewees were asked whether their views have changed and why.

Data Analysis

Data analysis began after the conclusion of the study and comprised four phases.

Phase I: HOS course profiles. The instructor interview transcripts, course syllabi, lecture audio-tapes, and field notes were used to generate a profile for each HOS course. Each profile included descriptions of (a) the course objectives, topics covered, readings and assignments, classroom dynamics, and instructional approach, (b) the instructor's priorities, and his/her views about the relationship between science, HOS, and science teaching, and (c) whether, to what extent, and in what ways were various aspects of NOS explicitly addressed.

Phase II: Establishing the validity of NOS questionnaire. The questionnaires and interview transcripts of students in the random sub-samples and focus group were used to establish the validity of the questionnaire in assessing participants' NOS views. The questionnaires completed at the beginning of the term were analyzed first. In this analysis, each participant was treated as a separate case. Each questionnaire was used to generate a summary of the respondent's conceptions of NOS. This process was repeated for all the questionnaires. After this initial round of analysis, the generated summaries were searched for patterns or categories. The generated categories 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. These categories were employed to generate a profile of the participants' views of NOS.

The same process was repeated with the first sub-sample interview transcripts, and resulted in a separate profile of NOS conceptions for the same group of participants. Next, the profiles generated from the separate analyses of the questionnaires and the corresponding interviews were compared and contrasted. Good agreement between the two profiles was obtained. A similar agreement was obtained when the whole process was repeated using the questionnaires and corresponding interviews completed at the end of the term by students in the second sub-sample and focus group. These results indicated that the researchers' interpretations of participants' responses to the open-ended questionnaire were faithful representations of those participants' NOS views as articulated during individual interviews. As such, the next phase of data analysis was undertaken.

Phase III: Analysis of NOS questionnaires. The questionnaires of participants' who responded to both the pre- and postinstruction administrations were analyzed. Two summaries, pre- and postinstruction, were generated for each participant's conceptions of NOS. Each summary was coded under the various aspects relevant to this study including: (a) the course in which a participant was enrolled; (b) the participant's background, including class-standing, and science, HOS, and philosophy of science background; and (c) whether the participant's views were consistent with current conceptions of NOS prior to enrolling in a HOS course. It should be noted that having a view "consistent" with current NOS conceptions was determined on an aspect-by-aspect basis. That is, students included in this group did not necessarily have comprehensive and informed views of NOS. Some students only had adequate conceptions of the tentative nature of scientific knowledge, while others had adequate conceptions of several aspects of NOS.

In order to answer the questions of interest, individual summaries were used to construct a profile of the views of a certain group of students. These groups included, for example, students in a particular HOS course, or students with a framework consistent with current conceptions of NOS prior to enrolling in a HOS course. The appropriate profiles generated were compared and contrasted in the attempt to answer a question of interest.

Phase IV: Answering the research questions. First, the question regarding the influence of HOS courses on students' NOS conceptions was answered for each HOS course individually. For each course, participants' pre- and postinstruction NOS profiles were compared and contrasted to establish whether, to what extent, and in what ways each course influenced students' views of NOS.

Second, analyses focused on identifying the HOS course aspects that were related to changes in students' NOS conceptions. Once the impact of each HOS course on students' NOS views was assessed, it was possible to relate the resultant changes to particular course aspects. For example, if it was determined that students' views were impacted to a greater extent in a small, discussion-oriented class setting as compared to a large, lecture-oriented class setting, then inferences about the potential influence of classroom dynamics on students' views could be made. It should be noted that inferences generated from these analyses were dependent on whether, first, student views were changed to various extents in the investigated courses and, second, that the courses actually differed on an aspect of interest, such as explicit attention accorded to NOS.

Third, data analyses focused on assessing the impact of having an adequate conceptual framework of NOS prior to enrollment in HOS courses on participants' postinstruction NOS views. Analyses were conducted for each course individually: Pre- and postinstruction profiles were generated for two groups within each course. The first group was one judged to have, upon enrolling in the investigated course, more current conceptions of one or more aspects of NOS. The second was a group judged to have less adequate views of NOS. Changes in each group's NOS views, if any, were described and patterns of change were compared and contrasted.

It should be noted that for participants enrolled in a certain course with adequate views of one or more aspects of NOS, a positive influence of that course was assessed in terms of the extent to which these initial understandings have been enriched. Enriched understandings were assessed by the participants' abilities to, upon completing the investigated course, articulate their views more clearly and use historical materials covered in the course to provide relevant examples to support or elaborate on their views.

Results

Participants' Pre-Instruction NOS Views

This section presents a summary of participants' views concerning the tentative, empirical, inferential, creative, and subjective (theory-laden) NOS. Additional aspects include the lack of a single recipe-like method for "doing" science, and the functions of, and relationship between scientific theories and laws. In particular, the explanatory function of scientific theories and their role in guiding research are highlighted. Three additional aspects emerged from analyses of participants' questionnaire and interview responses: The aim and structure of scientific experiments, the logic of hypothesis and theory testing, and the validity of observationally based (as opposed to experimentally based) scientific disciplines.

Almost all participants held naïve views of many of the presently emphasized NOS aspects. Many of the participants' misconceptions were consistent with those reported in a relatively extended line of research that assessed high school and college students' NOS views over the past 45 years (e.g., Abd-El-Khalick & BouJaoude, 1997; Aikenhead, 1973; Bady, 1979; Cotham & Smith, 1981; Gilbert, 1991; Horner & Rubba, 1978, 1979; Mackay, 1971; Rubba, 1977; Rubba & Anderson, 1978; Rubba, Horner, & Smith 1981; Wilson, 1954).

Participants' NOS views in the three HOS courses were not different in any appreciable manner. Moreover, the NOS views of the preservice teachers enrolled in both the Evolution and Methods courses were not different from the views of those only enrolled in the latter course. However, compared to participants enrolled in the HOS courses, all preservice teachers held views that were more consistent with current conceptions of some of the target NOS aspects. Consequently, the present section summarizes and compares the pre-instruction NOS views of participants enrolled in the Evolution, Controversy, and Survey courses (excluding the 10 preservice teachers enrolled in the Evolution course) with those of participant preservice science teachers. These results are encapsulated in Table 2.

Table 2
Major trends in NOS views of participant HOS course students and preservice teachers

	Students in HOS Courses ($n = 166$)		Preservice Teachers ($n = 15$)	
NOS Aspect	% Naive	% Informed	% Naive	% Informed
Tentative NOS	90	7	7	93
Empirical NOS	82	4	40	53
Myth of "The Scientific Method"				
Without prompts	25	—	25	—
When specifically asked[a]	85	15	14	86
The experimental approach				
General goal and/or structure	81	11	67	33
Role of prior expectations[a]	72	28	73	27
Validity of observationally based disciplines	70	25	93	7
Scientific theories				
Well-supported nature	77	4	86	14
Explanatory function	67	33	40	60
Role in guiding research	87	13	86	14
Nature of theory testing	77	14	80	20
Scientific theories and laws				
Validity: The laws-are-certain fable	90	10	93	7
Perceived functions and relationship	97	3	86	14
Creative and imaginative NOS	85	15	86	14
Inference and theoretical entities				
Case of atomic structure	70	30	37	73
Case of biological species	84	16	86	14
Theory-laden NOS	62	17	53	47

Note. Percentages of informed and naïve views for a certain NOS aspect do not always add up to 100% given that some participants' responses were not coded into the major patterns or themes represented in this table.
[a]Based on data collected during individual interviews with a random sub-sample of participants.

In the following sections, codes are used to identify individual participants. Each code comprises a numerical number (numbers run from 1 to 181), and one or two letters, which indicate the course(s) in which a participant was enrolled. The letters "C," "E," "M," and "S," refer to the Controversy, Evolution, Methods, and Survey courses, respectively.

Tentative NOS. About 90% of the HOS course participants did not seem to believe that scientific knowledge is tentative. They either explicitly or implicitly indicated that science differs from other disciplines of inquiry in that scientific knowledge is definitive, correct or "proven" true. As one participant put it, "what makes science different from other disciplines of inquiry is the fact that it holds universal truths rather than a view of the truth according to certain individuals" (E076, prequestionnaire). By comparison, almost all preservice teachers (93%) ascribed to a tentative view of science. Many explicitly noted that the "one thing that is certain about science is that it will always change" (ME08, prequestionnaire).

Empirical NOS. A large majority of the HOS course participants (82%) demonstrated inadequate views of the empirical NOS. Many believed that tangible data could be used to "prove" the "truth" of scientific claims. They indicated that "science is different . . . because it uses concrete facts that have been proven/can be repeated and seen by someone else to get a right or wrong answer" (S053, prequestionnaire). Others advanced that science is solely based on "observations" to the exclusion of other personal, social or cultural factors. They noted that scientific knowledge "is the facts as they are finally presented without any kind of human interpretation. In religion and philosophy we interpret everything and not just take it for how it is plainly right there as we see it" (E093, pre-interview).

Only a small minority of the HOS course participants (4%) explicitly noted that even though science relies on observation, there is much in science that is based on beliefs, assumptions, and the nonobservable. And "even though science can be more concrete and observable, this is not always the case when we're talking about magnetic fields or something along those lines" (S056, prequestionnaire).

More than half of the preservice teachers elucidated similarly inadequate views. However, by comparison to 4% of the HOS course participants, 40% of preservice teachers explicated adequate conceptions of the empirical NOS. They indicated that "in both science and religion there is faith . . . that certain principles or certain bodies of knowledge are in fact true. [However], for science . . . you are going to have to back it up with some empirical evidence" (ME10, pre-interview).

"The Scientific Method." Without any prompts, an equal percentage (about 25%) of the HOS course participants and preservice teachers noted that science has "a particular method of going about things, the scientific method" (E116, prequestionnaire). However, only a minority of preservice teachers (14%) expressed this view when specifically asked during the pre-instruction interviews. The remaining student teachers indicated that there is "not a certain method to go about . . . research, obviously" (M017, pre-interview). By comparison, when asked, a large majority of the HOS course interviewees (85%) indicated that scientists follow "The Scientific Method" or other sets of logical and orderly procedures.

The Experimental Approach. As much as 81% of the HOS course participants did not demonstrate adequate conceptions of the general goal and/or structure of scientific experiments.

Some participants did not ascribe to experiments any element of control, manipulation, intervention, or even contrived observation carried out under reproducible conditions (see Bernard, 1957; Diamond, 1986). They indicated that an experiment "does not always involve intervention or manipulation . . . we can just do observational stuff" (E150, pre-interview). Other participants did not explicate a clear aim for conducting experiments or believed that experiments are conducted to "prove a proposed theory" (C179, prequestionnaire) or to "see if it [a theory] is . . . wrong or right" (S046, prequestionnaire), thus providing definitive answers regarding the "truth" of hypotheses or theories. Only a small minority of the HOS course participants (11%) noted that "an experiment is a controlled approach to test the validity of a theory or hypothesis. No experiment can ever fully validate a theory as fact . . . so experiments are constantly refined in an attempt to substantiate the implications of a theory" (E119, prequestionnaire), thus demonstrating clear understandings of the general intent and structure of scientific experiments.

Additionally, only about 28% of participants explicated adequate views of the crucial role of prior expectations in designing and conducting scientific experiments:

> If you are going to organize the experiment you sort of need to know what you are looking for. I always think that they [scientists] . . . will have an idea of where the results would lie . . . In order to organize an experiment you need to know what is going to come out of it or it wouldn't really be a test method. I don't know how you would organize a test or something if you don't have a general idea about what you are looking for. (S055, pre-interview)

Moreover, only 25% of the HOS course participants thought that manipulative experiments are not required for the development of scientific knowledge and demonstrated, through providing adequate examples, a clear understanding of the fact that several scientific disciplines are observational in nature and that many powerful scientific theories, such as Darwin's theory of evolution, rest solely on observational evidence. Preservice teachers' understandings of the above aspects were not different from those of the HOS course participants (see Table 2).

Scientific theories. About 77% of the HOS course participants indicated that theories do change. However, an equal percentage of participants did not provide examples or provided inadequate examples to substantiate this position. Moreover, almost all participants attributed theory change solely to "new information and technological advances which allow increased accuracy in experimentation" (C179, prequestionnaire).

Only 6% of the students recognized that new ideas, and social and cultural factors might also play a role in theory change. As one participant noted, "Theories change because one person or a group of people act out of context basically . . . Also, the reasons we accept or reject theories are so much tied to context in a historical and social–political way" (E155, preinterview). As far as the functions of theories are concerned, only 33 and 13% of participants recognized the explanatory function of scientific theories and their role as guiding frameworks for research, respectively.

A disconcerting pattern was that about 77% of participants did not demonstrate adequate understandings of the well-supported nature of scientific theories. Many noted that "a scientific theory is just an idea about how something works" (C172, prequestionnaire). Only 4% expressed the more informed view that in science "the word theory is used differently than in the general population. It does not mean someone's idea that cannot be proven. It is a concept that has considerable evidence behind it and has endured the attempts to disprove it'' (E137, prequestionnaire).

A majority of participants also lacked in their understanding of the nature of theory testing. They did not seem to understand that only indirect evidence could be used to support theories. Alternatively they indicated that a ''theory is something that cannot be tested. For example, to prove the theory of evolution to be true, this would take scientists roughly a million years for speciation to occur. No one has that kind of time'' (E110, prequestionnaire).

By comparison, 20% of preservice teachers noted that in addition to new evidence and technologies, theories might change due to ''the reinterpretation of extant data . . . and as perspectives and values change'' (ME10, prequestionnaire). About 80% provided adequate examples of theory change and 60% recognized the explanatory function of theories. Only 14%, however, explicated informed views of the well-supported nature of theories and their role in guiding research. Finally, 20% of preservice teachers held naïve views of the nature of hypothesis and theory testing.

The difference and relationship between scientific theories and laws. Consistent with their misconceived notion of the tentative NOS, about 90% of the HOS course participants believed that scientific laws are absolute or certain. These participants thought ''of a scientific law as something that has been proven, and therefore will not change because it is true'' (E164, prequestionnaire). About one-third of these participants provided inadequate examples of scientific laws. Indeed, ''Murphy's law'' and that ''a methyl group (CH_3) will always be a methyl group,'' were given as examples of scientific laws. Additionally, 97% of participants held a hierarchical view of the relationship between scientific theories and laws whereby ''a scientific law is a theory that has been accepted by all scientists and has been proven again and again over time to be true'' (E089, prequestionnaire).

By comparison, the greater majority of preservice teachers (86%) demonstrated adequate understandings of the functions of, and relationship between scientific theories and laws. They noted that a ''scientific law states, identifies or describes relationships among observable phenomena, [whereas] scientific theories are inferred explanations for observable phenomena'' (ME13, prequestionnaire). Only two preservice teachers (14%) held a hierarchical view of this relationship and one (7%) seemed to believe that laws are absolute. Finally, the greater majority of student teachers (93%) provided adequate examples of scientific laws.

The creative and imaginative nature of scientific knowledge. The HOS course participants' and preservice teachers' views did not differ in this regard. Ninety percent of all participants indicated that imagination and creativity are needed in scientific investigations, but assigned the use of these aspects to various stages of such investigations. Forty percent of participants thought that imagination and creativity permeate all stages of investigation, another 40% believed that their use is limited to the planning and design stages, and 15% noted that these aspects are used in all stages save data collection.

Nonetheless, the majority of all participants (70%) did not use imagination and creativity to refer to the *invention* of explanations, models or theoretical entities. Rather, students ascribed various other meanings to the terms ''imagination and creativity in science'' including being ''resourceful,'' ''skillful,'' ''open-minded and curious,'' ''using appealing ways to present results rather than being cut and dry,'' and ''not copying other scientists' designs and experimental procedures.'' Only about 16% of participants used these terms in the more informed sense of inventing models, theories, or ''novel ideas . . . to explain why certain results were observed''

(E088, prequestionnaire). Finally, it is noteworthy that almost all participants (94%) did not provide any examples or provided inadequate examples to support their views concerning the use of imagination and creativity in science.

Inference and theoretical entities in science. Only 30% of the HOS course participants demonstrated adequate understandings of inference and inferential entities. These participants noted that atoms cannot be directly observed and that only indirect evidence is used to determine the structure of an atom:

> Scientists have come upon the current model of an atom by testing, manipulating, and observing the ‘‘behavior’’/properties of an atom based on charge properties and relationships with other atoms and molecules. Scientists are fairly certain about the structure, but again it is only a theory because scientists have never seen an atom and its orbitals. (E081, prequestionnaire)

However, an alarmingly high percentage of participants (25%) thought that ‘‘scientists are very certain [about atomic structure], for they have observed the structure of atoms using powerful microscopes to actually peer at the structure of atoms of various elements and count the protons, neutrons, and electrons’’ (S036, prequestionnaire). By comparison, a majority of preservice teachers (73%) indicated that atomic structure is a ‘‘model constructed through experimentation and inference. It is like inspecting the soil morphology layers . . . You can’t open the whole earth and look at it. You have to make observations of parts of it and [then] to infer, to connect the dots’’ (M016, preinterview).

However, like other participants, preservice teachers did not demonstrate adequate views of the inferential and theoretical nature of scientific constructs in their discussions of the concept of ‘‘species.’’ More than half of all participants indicated that scientists are certain about their characterization of species. Only a minority (16%) noted that ‘‘species is a human convention, an ‘artificial’ concept created to convey and communicate about organisms with others. ‘Species’ is a very static term for something that is unstable in reality’’ (C184, prequestionnaire).

The subjective or theory-laden nature of scientific knowledge. About 62% of the HOS course participants attributed the dinosaur mass-extinction controversy (see Appendix A) solely to the lack of evidence. They noted that the ‘‘data is limited at best. Some people use the evidence to support one theory while others use that evidence to support another theory. While neither can prove the other wrong, neither can provide enough evidence to prove themselves right’’ (S043, prequestionnaire). Thus, these students failed to recognize that factors other than ‘‘data’’ might play a role in generating and supporting scientific claims.

Only about 17% of participants explicated adequate understandings of the theory-laden NOS indicating that scientists’ disciplinary training and educational backgrounds, personal experiences, preferences, and opinions, and basic guiding assumptions and philosophies influence their perception and interpretation of the available data:

> Scientists, as individuals, have widely varying intellectual, emotional, and religious backgrounds. Also, no one is completely without bias in some direction. This means that, even as all scientists look at the same body of verifiable data, they will draw different conclusions. They may be using their intuition, they may have previous ideas, or they may weight the importance of the data differently. (S028, prequestionnaire)

Some participants noted that disciplinary commitments and preferences might also lead scientists to place disproportionate emphases on various ‘‘parts’’ of the data. A few (3%) referred to specific disciplines and explanatory preferences that were relevant to the extinction controversy. They noted that one group of scientists were ‘‘more into geology and more into terrestrial things and they are going to come up with the volcanic hypothesis. And the other group is more extraterrestrial . . . and they are going to think that it was a meteor’’ (S030, pre-interview). By comparison, appreciably more student teachers (47%) demonstrated an understanding of the theory-laden nature of scientific knowledge.

Finally, consistent with prior research findings, all participants' views of NOS were not related to their gender (e.g., Wood, 1972), class standing, and science backgrounds (e.g., Carey & Stauss, 1969; Scharmann, 1988a, 1988b; Wood, 1972). Additionally, in this study, participants' NOS views were not related to their history and philosophy of science backgrounds. It should be emphasized, however, that the overwhelming majority of participants who had any background in history and/or philosophy of science indicated that they had completed only one course in one of these disciplines and/or the other.

Changes in Participants' NOS Views

An examination of Table 3 indicates that very little change was evident in participants' NOS views at the conclusion of the study. Moreover, almost all the changes in the individual participant's conceptions were related to only one aspect of NOS or another. The views of only four participants (3%) changed with regard to two or three of the presently emphasized NOS aspects. Additionally, as expected, no changes were evident in the views of preservice teachers only enrolled in the Methods course given that NOS was not addressed in this course. As such, any changes in the views of preservice teachers simultaneously enrolled in the Methods and Evolution courses could be attributed to their experiences in the latter course.

The present section describes the changes that were evident in the views of participants enrolled in each of the participant HOS courses. In addition, this section summarizes those participants' views that were enriched. In their pre-instruction responses, many participants failed to provide, or provided inadequate examples from history or practice of science to support

Table 3
Changes in participants' views of the emphasized NOS aspects

			Evolution Course					
	Survey Course (*N* = 45)		Students (*N* = 103)		Preservice Teachers (*N* = 10)		Controversy Course (*N* = 18)	
Number of NOS Aspects[a]	*n*	*P*	*n*	*P*	*n*	*P*	*n*	*P*
1	6	14	28	27	4	40	3	17
2	1	2	1	1	1	10	0	0
3	0	0	0	0	1	10	0	0

Note. *N* refers to the total number of participants enrolled in the specified course whereas *n* refers to the number of participants whose views have changed with regard to the corresponding number of NOS aspects. *P* = percentage.
[a]The views of participants in each row changed with regard to the corresponding number of NOS aspects. For example, in the row labeled ‘‘1,’’ participants' views have changed with regard to one *or* another of the NOS aspects emphasized in the present study.

their views. Participants' views of a NOS aspect were considered to be enriched if those participants provided in postinstruction questionnaires specific examples discussed in a HOS course to support or defend their views. It should be noted that, save providing adequate examples, these participants' views were indistinguishable from their pre-instruction views.

The Survey Course. Change was evident in the views of seven Survey course participants (16%). Nonetheless, the observed changes in the views of six were only with regard to one aspect of NOS or another, and the views of the seventh participant with regard to two NOS aspects. One participant who did not endorse the validity of nonexperimental scientific disciplines at the outset of the study, noted at its conclusion that experiments are not necessarily required for developing scientific knowledge since "astronomy and cosmology are largely experiment-free" (S043, postquestionnaire). Three other participants seemed to have internalized the notion that new ideas also play a role in theory change "like when they [scientists] had the geocentric model . . . and this went well with the thinking of that time. Later the theory changed into the heliocentric model and that went on with new thinking, new observations, and new ideas" (S053, postinterview).

Three more participants demonstrated adequate conceptions of the dynamic and theoretical nature of the concept of species indicating that it is not necessarily a characteristic of nature. Rather, "species" is a human-made tool intended to help scientists "understand and communicate about organisms we share our world with" (S055, postquestionnaire). Also, one of these latter participants who had attributed the mass-extinction controversy solely to the lack of data, noted in her postinstruction responses that factors, such as background knowledge and personal preferences, do influence the conclusions scientists derive from available data. Moreover, it is noteworthy that with the exception of one student (2%), none of the Survey course participants used any of the examples discussed in the course to support any of their NOS views. Finally, when explicitly asked during the postinstruction interviews, all 10 Survey course interviewees indicated that their views of NOS have not changed.

The Controversy Course. The views of three Controversy course participants (17%) changed with regard to one aspect of NOS or another. One participant demonstrated better understandings of the theory-laden NOS. He indicated that "scientific theories provide us with a way of viewing the universe with a certain framework in mind" (C172, postquestionnaire), and realized the importance of having theoretical expectations prior to designing or conducting experiments. Moreover, in his discussion of the mass-extinction controversy, this participant recognized the role of scientists' theoretical commitments and personal beliefs in guiding their interpretation of data, since "scientists are 'reading' the data and drawing conclusions with their theory in mind." As such, scientists who believe in "extraterrestrial causes of extinction read the data with reference in mind to meteorites and their associated evidence of crash . . . Those believing in terrestrial causes, view the evidence in terms of their theory of volcanic eruptions . . . and evidence of their occurrences" (C172, postquestionnaire). It should be noted that this participant chose the extinction controversy as the topic for his term paper in the Controversy course. A similar but less pronounced change was evident in the views of a second participant who also wrote her term paper on the mass-extinction controversy. The third participant explicated better understandings of the controlled nature of scientific experiments.

The conceptions of five other participants (28%) were enriched as evident by their use of examples or case studies discussed in the Controversy course to support their views. Three of these participants referred to the shift from a geocentric to a heliocentric conception of the solar system or the change from Newtonian to relativistic physics as examples of theory change. A fourth participant provided the Michelson–Morley experiment and the mass-extinction controversy as examples to respectively support his pre-instruction views about the use of creativity in data collection and the role that scientists' backgrounds and education play in their interpretation of data. A fifth participant referred to the dinosaur extinction controversy and the question of human origins to support her preinstruction views regarding the use of imagination and creativity in developing theories and explanations. Finally, when specifically asked during postinstruction interviews, four of five interviewees indicated that their views have not changed.

The Evolution Course. Change was evident in the views of 35 participants (31%): 29 students and six preservice teachers. Of those 29 students, the views of 28 changed only with regard to one aspect of NOS or another. The views of one participant changed with respect to two NOS aspects. Additionally, the views of 18 participants (16%) were enriched. Since preservice teachers are of special interest for the purposes of this study, changes in their NOS views are discussed separately from those of other students enrolled in the Evolution course.

At the outset of the study, 12 participants indicated that scientific theories do not change or are only modified and refined. Four of these participants now noted that "scientific theories change all the time [due to]...new info from new technologies and research" (E127, postquestionnaire). Five other participants recognized a role for new ideas, beliefs, theories or social and cultural factors in theory change. An additional six participants emphasized the importance of scientific theories as frameworks for guiding future research. These participants noted that scientific theories, such as the theory of evolution, "act as catalysts:" They generate new questions, open new avenues for research, and direct the thinking of investigators along certain lines. Through pursuing such new lines of investigation, advances in various scientific areas are sometimes achieved. Moreover, citing evolutionary theory, five other participants demonstrated better understandings of the validity of scientific claims and theories derived from, and supported by observational (as compared to experimental) evidence.

Change was evident in the views of six other participants regarding the concept of "species." These participants now indicated that scientists are not certain about their characterization of species, which is a man-made concept. They noted that varieties abound in nature and "sharp" lines might not exist between closely related species. The influence of reading Darwin's *Origin of Species* was evident in these participants' responses:

> I've never thought about it actually until I've read the *Origin of species* and Darwin talked a lot about that, and then I started thinking what is the difference between a variety that we've talked about in class and a species, and I think that we don't have a line. I think...our brain naturally categorizes things...So, I think it is natural for us to want to group things together. (E117, postinterview)

Three other participants demonstrated better understandings of the theory-laden nature of scientific knowledge. Referring to specific examples discussed in the Evolution course, they argued that scientists' training influences their acceptance or rejection of scientific theories. For instance, they thought that scientists interpret the same data differently because they might be "trained to think in particularly different ways...So the French did not believe or accept Darwin's natural selection...[because they] were trained and influenced by Cuvier who promoted the species type concept and catastrophism" (E164, postquestionnaire). Finally, one of these latter participants explicated more adequate views of the creative NOS. She noted that Darwin, like other scientists, used "imagination and creativity...to formulate his theory that explained all his observations and the observations of others about species and geographical distribution'' (E120, postquestionnaire).

The views of 15 other Evolution course participants were enriched. Twelve of these students were now able to support their pre-instruction view that scientific theories change with an adequate example; change in evolutionary theory. Two other students cited the same theory to support their otherwise unsubstantiated pre-instruction view concerning the validity of observationally based scientific claims. Finally, one other participant who had explicated an adequate view of the distinction between theories and laws at the outset of the study now supported this view with examples. She noted that a ''law describes a regularity that occurs under a specific set of conditions like the law of independent assortment . . . A theory explains and synthesizes a large body of knowledge . . . Evolution synthesizes genetics, geology, population biology, ecology, and taxonomy'' (ES01, postquestionnaire).

When specifically asked during postinstruction interviews, 14 of 18 interviewees indicated that their views about science have not changed. One of these interviewees noted that the Evolution course had enriched his views with specific examples that would allow him to better communicate his beliefs about science. Four other interviewees felt that they had developed better understandings of evolutionary theory. Additionally, one of these latter four interviewees noted that his views about the nature of scientific theories had changed substantially.

As indicated in Table 3, of 10 preservice teachers in the Evolution course, change was evident in the views of six. However, the views of four changed with respect to one aspect of NOS or another. At the conclusion of the study, two preservice teachers emphasized that theories ''guide future scientific endeavors. For example Darwin's theory caused lots of people to do research in the area of genes and also made people more interested in determining the age of the earth'' (ME05, postquestionnaire). Two other preservice teachers now indicated that, in addition to the accumulation of new evidence and technological advances, new ideas and reinterpretation of extant data play a role in theory change. A third student teacher noted that cultural factors, such as dominant philosophies and the prioritization of ''scientific problems'' within certain scientific and cultural contexts, influence the acceptance of new theories.

Change was also evident in five preservice teachers' views of the construct of species. These participants now noted, ''After reading the *Origin* I don't think we are certain [about species] at all . . . We made these groups, and there are different levels of putting animals in categories. It is a human idea and it could change'' (ME08, postinterview). Finally, two preservice teachers demonstrated better understandings of the creative and imaginative nature of scientific knowledge indicating that ''Darwin had to 'create' the idea of Natural Selection. He put together all of his observations and research and had to imagine what mechanism could be responsible for the creation of so many varied species'' (ME06, postquestionnaire).

Additionally, the views of three student teachers (30%) were enriched. Two cited the theory of evolution as an example of a scientific theory that changed through time, and the third to support his view of the validity of observationally based scientific theories. Finally, when specifically asked during the postinstruction interviews, only one preservice teacher noted that her views had changed. The remaining four interviewees noted that their views had been elaborated.

Pre-instruction Interviews and Changes in Participants' NOS Views. The pre-instruction interview might have served as a treatment, and changes in interviewees' views could be attributed to these interviews rather than to experiences in the HOS courses. To assess such a possibility, two groups of participants were compared: Those who were interviewed at the beginning of Fall term and those who were not interviewed. Comparisons indicated that the percentages of participants whose views had changed in the two groups were not different. Additionally, there were no trends in the changes that were evident in the case of participants who sat though a pre-instruction interview versus those who did not. As such, there is no evidence to indicate that preinstruction interviews impacted participants' post-instruction views.

The Relationship between Changes in Participants' NOS Views and their Pre-Instruction Views

At the outset of the study, a majority of participants held inadequate views of several of the presently emphasized NOS aspects (see Table 2). Table 4 presents the number and percentage of participants in the HOS courses and focus group who demonstrated adequate conceptions of certain subsets of these aspects. The figures shown in Table 4 were obtained by counting the number of participants in each HOS course who explicated informed views of 1, 2, 3, etc., of the target NOS aspects. For example, at the beginning of Fall term, 28 Evolution course participants and 12 Survey course participants elucidated adequate views of only one aspect of NOS or another, while seven Evolution course participants held informed views of three of the emphasized NOS aspects. It should be noted that Table 4 does not present cumulative numbers and percentages of participants. Rather, it presents the number and percentage of participants who only held adequate views of the corresponding number of NOS aspects. For example, all preservice teachers in the focus group held adequate views of three or more NOS aspects. Indeed, two preservice teachers held adequate views of three NOS aspects, and six others held adequate views of four aspects. The remaining two student teachers explicated adequate views of five and seven NOS aspects respectively (see Table 4).

Participants' views were largely fragmented and hardly any patterns were evident in the subsets of NOS aspects presented in Table 4. Only one noteworthy pattern was evident in the case of the 10 preservice teachers enrolled in the Evolution course: Eight of these participants held adequate views of four or more NOS aspects, and a set of four aspects were common to the

Table 4
Number and percentage of participants with adequate views of subsets of the emphasized NOS aspects

NOS Aspects	Survey		Evolution		Controversy		Focus Group	
	n	*P*	*n*[a]	*P*[a]	*n*	*P*	*n*	*P*
1	12	27	28	27	3	17	0	0
2	3	7	12	12	1	6	0	0
3	3	7	7	7	1	6	2	20
4	0	0	0	0	1	6	6	60
5	1	2	3	3	1	6	1	10
6	0	0	1	1	0	0	0	0
7	0	0	0	0	0	0	1	10
8	0	0	0	0	0	0	0	0

Note. *n* represents the number of participants with adequate views of the corresponding number of aspects of the NOS and not the cumulative number of participants.
[a]Number and percentage of participants enrolled in the Evolution course excluding preservice science teachers in the focus group.

views of seven of them (88%). These aspects included an understanding of the tentativeness of science, the role of inference in science, and the functions of, and relationships between theories and laws. This commanlity is most likely related to the explicit NOS instruction that these student teachers received in the Summer Methods course.

Change in participants' NOS views seemed to have been compromised by their pre-instruction conceptions, which have developed over years of high school and college science experiences. This point was clearly communicated by several participants. When asked during the postinstruction interview whether his views about science have changed, one participant replied in the negative. He noted, "I've taken so many science classes . . . I think that I am at the point where one more class even if it is history of science and analyzing science . . . it really wouldn't change the way I view science" (E083, postinterview).

Two examples would suffice to demonstrate the tenacity with which many participants held some of their pre-instruction NOS views. Twelve Evolution course participants had indicated at the beginning of the study that scientific theories do not change or are merely elaborated. Theory change was a major theme of the Evolution course, and the course professor made several explicit references to the tentative nature of theories. Despite all that, eight of these 12 participants (67%) still maintained at the conclusion of the study that "a scientific theory does not change through time . . . It can however be expanded or added on to with the development of modern science" (E133, postquestionnaire).

Another example of a diehard conception relates to participants' view that scientific claims could be proven "true." The Evolution course professor explicitly indicated at several instances throughout the course that scientists do not "prove" scientific theories and that theories are not "true" or "false." Rather, scientists aim to substantiate theories and, consequently, theories are well corroborated or weakly supported and not "right" or "wrong." Six participants indicated in their responses to the first item on the postinstruction NOS questionnaire that "scientific theories can't be proven but can be made strong or weak by bodies of evidence gathered by observation or experimentation" (E084, postquestionnaire). At first, such responses are reassuring since these participants seem to have internalized the notion that scientific theories could not be "proven." However, in their responses to the fifth item on the questionnaire or during the interview, all six participants noted that scientific theories become laws when they are "proven true."

Table 4 indicates that the greater majority of participants entered the HOS courses practically lacking any views consistent with current NOS conceptions. Indeed, more than 90% of all participants enrolled in the HOS courses either held views that were entirely inconsistent with, or held adequate views of one, two, or three of the presently emphasized NOS aspects. Change was evident in the views of 26% of these participants. Moreover, the views of 12% were enriched. By comparison, 15 participants (9% of all HOS course participants) held adequate views of four or more NOS aspects (see Table 4). Change was evident in the views of eight of these participants (53%). Moreover, the views of seven (47%) were enriched. It should be noted that eight of these 15 participants were preservice teachers.

As such, change (mainly with respect to only one aspect of NOS or another) was evident in the views of *relatively* more participants who entered the HOS courses with adequate views of four or more NOS aspects. Indeed, the percentage of these latter participants whose views had changed is twice as large as the corresponding percentage among participants who entered the HOS courses with relatively less adequate NOS views. Similarly, the views of a much larger percentage of participants in the former group (47%) were enriched relative to the corresponding percentage in the latter (12%). This pattern was even more pronounced in the case of preservice teachers in the Evolution course. Eight of these 10 preservice teachers demonstrated adequate views of four or more NOS aspects at the outset of the study. The views of all eight preservice teachers were influenced: The views of six (75%) were changed and the views of three (37%) were enriched.

This pattern in the data is very interesting. It is consistent with the notion that students who enter HOS courses with a framework consistent with current NOS views are more likely to leave such courses with more adequate and enriched views. Nonetheless, the significance of this pattern is limited by two factors. First, the number of participants with adequate views of four or more NOS aspects is very small relative to the number of all participants. The corresponding number of preservice science teachers in the focus group is even smaller. As such, the noted pattern might be an artifact of idiosyncratic attributes of a few participants rather than a reflection of a more significant trend. Second, the cut-off number of ‘‘four NOS aspects’’ is totally arbitrary. This number was chosen because it renders visible a seemingly important pattern in the data. There are no substantial or coherent relationships between the certain sets of the four NOS aspects with which certain participants entered the HOS courses and the few changes that were evident in those participants' views.

The Relationship between Changes in Participants' NOS Views and Specific Aspects of the HOS Courses

Almost all of the changes that were evident in participants' NOS views could be directly related to those NOS aspects that were explicitly addressed in the respective HOS courses. First, change in the views of one Controversy course participant was related to the controlled nature of experiments, an aspect that the Controversy course professor explicitly articulated in her discussion of experiments at the outset of the course.

In their discussions of the mass-extinction controversy, two other Controversy course participants explicated more informed views of the influence of theoretical commitments and other personal attributes on the explanations that scientists advance to account for empirical observations. This controversy was one of the case studies explored in the course. However, it can be argued that such exploration did not engender a similar change in the views of the remaining 16 course participants. What is noteworthy, nonetheless, is that the aforementioned two participants further examined the mass-extinction controversy in their term paper for the course. As such, even though the extinction controversy was explored in the course, change in participants' views was evident in the case of those who had opportunities to further investigate and reflect on this specific controversy. In this regard, it should be noted that the Evolution course professor had discussed uniformitarian geology. However, he made no explicit references to the relationship between implicit assumptions and preferred explanations in this context, such as the relationship between the premises of uniformitarianism and geologists' preference for ‘‘terrestrial’’ explanations. Such relationship was not relevant to the story of evolution. None of the Evolution course participants linked this discussion of uniformitarianism to the mass-extinction controversy addressed in the ninth item on NOS questionnaire.

Second, the changes evident in the Evolution course participants' views, including preservice science teachers, were almost all related to aspects of the nature of scientific theories explicitly addressed in the course. Many of the observed changes were related to the notions that scientific theories are tentative and change through time; serve as frameworks for guiding research; and change *partly* due to new ideas or social and cultural factors. Another change in the views of a few Evolution course participants was related to the validity of observationally based disciplines and/or scientific theories. The course professor emphasized that evolutionary theory could not be directly tested through experimentation. Rather, he emphasized that scientists rely on observational evidence, such as fossils and geographical distribution of animal and plant species, to validate the theory.

Moreover, the views of a few other participants changed with respect to the notion of species. This change was directly related to participants' reading of the *Origin of Species* and ensuing discussions in the Evolution course. Finally, a few participants noted that subjective factors such as scientists' training and philosophical commitments influence their interpretation of data and acceptance or rejection of scientific theories. These participants discussed this NOS aspect in the specific context of the reception of Darwin's theory in France and Germany, which was discussed at some length in the Evolution course.

Third, the changes evident in the views of the Survey course participants were related to the role of new ideas and biases, both cultural and personal, in theory change and the explanations that scientists advance to explain observations of natural phenomena. It was indicated that this NOS aspect was the major theme that was explicitly discussed by the Survey course professor.

It was previously mentioned that relatively few changes were evident in the views of the HOS course participants. However, change was evident in the case of a relatively larger percentage of the Evolution course participants (31%) as compared to the corresponding percentages in the Survey (16%) and Controversy (17%) courses. Of the participant HOS courses attributes that could account for this observation, besides explicit attention given to NOS, the most likely ones are course objectives and instructor priorities. The Evolution course professor articulated an explicit commitment to help students develop adequate NOS views in general and of a few specific attributes of the nature of scientific theories in particular. The Survey and Controversy course professors did not explicitly express a similar commitment.

Finally, as previously indicated, the Survey course professor explicitly addressed the social and cultural embeddedness of science and provided several examples to this effect. However, contrary to expectations, the views of only few Survey course participants changed with respect to this NOS aspect. Participants enrolled in the Survey course might have perceived the works and examples presented in the course to be "nonscientific" by "modern" standards. These participants, it seems, were not successful in "putting on a different kind of thinking cap" when going through the course materials or thinking about the relevance of such material to understanding current scientific knowledge and practice.

Discussion and Implications

That the participant HOS courses had only minimal influence on students' NOS views is probably the most significant finding of this study. This finding does *not* lend empirical support to the assertion that coursework in HOS would improve students' NOS views (e.g., Conant, 1947; Duschl, 1990; Haywood, 1927; Klopfer, 1969; Klopfer & Watson, 1957; Matthews, 1994; Monk & Osborne, 1997; Robinson, 1969; Rutherford, 1964; Wandersee, 1992). To the extent that the three participant courses are representative of introductory or general college HOS courses, the present study indicates that one HOS course is not likely to enhance students' NOS views in any substantial way. This finding, nonetheless, seems counterintuitive. After all, HOS is the study of science and it aims to understand the workings of the scientific enterprise, and HOS courses deal with the development of scientific knowledge and disciplines. The present results, however, were not totally unanticipated and are explicable on several conceptual and empirical bases.

First, there seems to be some difficulty inherent in using HOS to help learners acquire an understanding of NOS. In HOS courses, students are usually presented with finished historical narratives in the form of readings or lectures. To be able to discern the subtleties of such narratives and perceive the associated ''lessons'' about NOS, students need, or are *expected*, to view and interpret the historical materials from within a conceptual framework that is sometimes radically different from their own, and more congruent with the worldview of the target scientist(s) and the associated historical period. Otherwise, if the historical narrative were viewed and indiscriminately judged from within the spectacles of present scientific knowledge and practices, then learners are likely to dismiss the presented historical scientific notions simply as wrong ways of explaining the natural world, rather than as notions advanced by earlier scientists in their attempts to understand natural phenomena.

Science educators who have assumed that coursework in HOS would automatically result in enhancing students' NOS views did not seem to recognize or appreciate the difficulty inherent in helping students make the prerequisite conceptual shift. The participant HOS course professors, nonetheless, recognized the importance of this crucial conceptual shift and attempted to address it. In particular, the Evolution course featured active attempts to help students perceive the course materials from within an alternative perspective.

A genuine effort and extended commitment, however, are often undertaken by historians of science to achieve the kind of conceptual shift necessary to make the historical approach useful for learning *about* science (Brush, 1969, 1979; Kuhn, 1977). It might be difficult for students and preservice teachers enrolled in HOS courses to achieve such a conceptual shift as a result of rather limited exposure to historical materials or engagement in historical research. Indeed, consistent with constructivist arguments (e.g., von Glasersfeld, 1979, 1989), students tend to perceive and interpret educational experiences from within their extant conceptual frameworks and prior knowledge. In the present context, participants seemed to have interpreted the historical narratives from within current scientific knowledge and practices rather than from within any other alternative framework with which they were presented. This was particularly evident in the case of the Survey course. The Survey course professor indicated that most of the students were judging the course materials from within present-day perspectives. In fact, almost none of the Survey course participants used any of the examples discussed in the course to support their views at the conclusion of the study. It seems that these participants did not perceive such examples as Ptolemy's astronomical system or Galen's humorial theory as relevant to their views of science.

As such, in the historical approach, students are expected to ''put on a different kind of thinking cap'' while going through the historical narrative. However, this might not be enough. To perceive the associated ''lessons'' about NOS, students should be able to ''step back'' to the present and discern the relevance of the historical narrative to the nature of current scientific knowledge and practice. This second conceptual shift might be as difficult for students as the first one is anticipated to be. In general, research indicates that students' cognition is primarily situated within the specific contexts in which learning has occurred and that students' are often not successful in transferring and applying the knowledge and understandings they acquire within one context to other similar contexts (Gage & Berliner, 1998). The failure to ''transfer'' NOS understandings was evident, for instance, in the case of participant preservice teachers. As noted earlier, these participants were able to discern the theoretical nature of a physical sciences concept, the model of the atom, by virtue of specific instruction they had received in the Summer Methods course. These preservice teachers, however, failed to apply their understandings to a similar concept from the biological sciences, namely the concept of species. Indeed, Gage and Berliner (1998) noted that if transfer of learning is desired, then the similarities between the context in which students were taught and the context to which their knowledge and understandings are expected to be applied should be explicitly identified. As such, if students are expected to discern ''lessons'' about NOS from historical narratives, then they should be helped to recognize the similarities between such narratives and current scientific practices.

A second factor that might explain the relatively limited influence of the participant HOS courses relates to the extent to which various aspects of NOS were accorded explicit attention in these courses. It was noted that such attention was, at best, limited. In this regard, the present results lend credence to the notion that explicitly addressing certain aspects of NOS within the context of HOS courses could be more effective than an implicit approach to enhancing students' views. This conclusion is corroborated by two observations. First, almost all the changes evident in participants' NOS views could be directly related to those NOS aspects that were explicitly addressed in the respective HOS courses. Second, compared to the Survey and Controversy courses, change was evident in a relatively larger percentage of the Evolution course participants in which NOS was accorded more explicit attention.

However, it might be argued that these results are not altogether congruent with the claim that explicitly addressing certain NOS aspects in the investigated courses was effective in enhancing participants' views. This argument could be based on the fact that a few aspects of NOS were explicitly addressed in the participant HOS courses. Nonetheless, change was evident in the views of only a few participants with regard to these aspects. As such, the claimed effectiveness of an explicit approach lacks empirical support.

Two elements serve to ameliorate concerns about the validity of the claim regarding the effectiveness of an explicit approach. First, it should be noted that this claim was made relative to the purported effectiveness of an implicit approach. Indeed, while the few changes evident in participants' views could be directly related to NOS aspects that were explicitly addressed in the respective HOS courses, none of these changes were related to the multitude of NOS aspects that were embedded in the historical narratives. None of the participants explicated any of these implicit "lessons" about NOS in their postinstruction responses. Second, in the present study, it was neither claimed nor expected that explicitly addressing certain NOS aspects in the participant HOS courses would result in changing the views of all students with regard to these aspects. It was rather expected that the views of relatively more participants would be influenced as was evident in the case of the Evolution course. The fact that NOS views of only a few participants were influenced as a result of instruction should not be surprising given the well-documented resistance of learners' misconceptions to change even in response to formal instruction (Wandersee, Mintzes, & Novak, 1994).

This latter discussion brings to light the third factor that might explain the relatively limited influence of the participant HOS courses even with regard to those NOS aspects that were explicitly addressed in these courses: At the outset of the study, the greater majority of participants held several misconceptions of many of the presently emphasized NOS aspects. Moreover, as noted earlier, these pre-instruction NOS views were held tenaciously by the majority of participants. Indeed, the interaction between learners' misconceptions of content and learning more accurate content is well documented in the science education literature (e.g., Anderson, Sheldon, & Dubay, 1990; Bishop & Anderson, 1990; Smith, Blakeslee, & Anderson, 1993; Wandersee et al., 1994).

A fourth factor that might explain the limited influence of the participant HOS courses relates to the courses' goals and objectives. The aim of enhancing students' NOS views might not always be accorded priority in HOS courses. In such courses, for instance, learning about the history of scientific disciplines and knowledge might be viewed as an end rather than a means to achieving other goals. Moreover, if HOS is viewed as a vehicle for achieving other objectives, teaching about NOS might be only one among several other objectives deemed important within the discipline of HOS.

It can thus be seen that several factors might impede the effectiveness of the historical approach in enhancing students' and preservice teachers' NOS views. It was argued earlier that one possible way to ameliorate the aforementioned "obstacles" is to provide learners with a conceptual framework consistent with current views of NOS prior to their enrollment in HOS courses. And since learners tend to interpret and make sense of new experiences from within their extant schemas, such a framework might help students, including student teachers, to interpret the historical narrative from within an alternative mindset, one that is more consistent with current views of NOS. This framework coupled with coursework in HOS could serve to reinforce, elaborate, and deepen student teachers' understandings of various aspects of NOS and to enrich these understandings with examples, metaphors, and stories. Indeed, data analyses revealed a pattern consistent with the suggestion that students who enter HOS courses with a framework consistent with current NOS views are more likely to leave such courses with more adequate and enriched views.

Implications of the Study

This study has implications for the use of HOS courses to help college students in general and preservice science teachers in particular develop adequate views of NOS. First, the study indicates that if historians of science aim to enhance students' NOS views, then an explicit instructional approach that targets certain NOS aspects can be more effective than an implicit approach. Historians of science need to explicitly guide students in the process of interpreting historical narratives from within alternative perspectives. Students also should be explicitly helped to discern relationships between any generalizations derived from the historical narrative and the nature of current scientific knowledge and practice.

It might be argued that an explicit approach entails imposing on students certain views of the scientific enterprise (e.g., Matthews, 1994). A more authentic learning experience, the argument would continue, would be to allow students to derive their own conclusions concerning NOS based on their exposure to historical narratives. However, our counter argument would be that certain views of NOS have *already* been imposed on students. It is highly unlikely that students have come to harbor the well-documented and persistent NOS misconceptions merely by internalizing implicit messages about science embedded in their high school and college science experiences. It is more likely that those students were explicitly taught certain naïve ideas about NOS. Indeed, students are, for example, often explicitly exposed to—if not taught, what Horner and Rubba (1979) dubbed the "laws-are-mature-theories fable." Students encounter in their science textbooks explicit generalizations such as, "A theory that has withstood repeated testing over a period of time becomes elevated to the status of a law" (Curtis & Barnes, 1985, p. 8). Moreover, the myth of a singular "Scientific Method" is propagated in many high school and introductory college level science textbooks (e.g., Emiliani, Knight, & Handwerker, 1989; Hewitt, 1998; Hill & Petrucci, 1996). As such, guiding students to internalize more informed views of NOS should not be viewed as an episode of formal indoctrination. Rather, it should be viewed as an attempt to empower them to further pursue and make sense of the workings of a rich and interesting intellectual endeavor, the scientific enterprise.

A second implication of this study is that an explicit approach might not suffice to substantially change students' entrenched misconceptions of NOS. A conceptual change approach (Clough, 1995; Hewson & Hewson, 1983; Posner, Srike, Hewson, & Gertzog, 1982) might be more effective. In the context of HOS courses, a conceptual change approach entails several stages. Students' views of certain NOS aspects are first elicited. Next, specific historical examples are used to help students discern the inadequacy of, and raise their dissatisfaction with some of their current NOS conceptions. Students are then explicitly presented with more adequate conceptions of the target NOS aspects. The historical narrative can then be employed to provide students with opportunities to perceive the applicability and fruitfulness of these newly articulated views in making sense of various aspects of scientific knowledge and practice in a variety of historical and disciplinary contexts. A conceptual change approach, it should be emphasized, is time-consuming and demands a specific commitment on the part of HOS course instructors to enhancing students' views of NOS probably at the expense of other instructional objectives.

Third, the results of the present study suggest that science educators *cannot* simply assume that coursework in HOS by itself is sufficient to help prospective science teachers develop desired understandings of NOS. Rather, it might be more fruitful for the needs of science teachers to enroll in courses that explicitly attempt to challenge their misconceptions of NOS *prior* to their enrollment in HOS courses. Such a course sequence might help preservice teachers develop more adequate and enriched NOS views. In the context of science teacher education, science methods courses that adopt an activity-based reflective explicit approach, augmented with elements from history and philosophy of science, could play a role in providing student teachers with a conceptual framework consistent with current conceptions of NOS before enrolling in HOS courses (see Akerson et al, 2000).

Fourth, science educators need to realize that HOS is an established discipline with its own legitimate agendas and priorities. It should not be assumed that the goals and objectives accorded priority in HOS courses are consistent with the needs of preservice science teachers. As such, a concerted effort should be undertaken on the part of science educators to initiate a discourse with historians of science interested in enhancing students' views of NOS. Such discourse could help make historians of science more cognizant of the needs of science teachers. More importantly, it might be fruitful to initiate collaborative efforts whereby specific NOS aspects explicitly emphasized in the context of teacher education courses are reinforced, elaborated, and enriched within the context of HOS courses through historical narratives explicitly geared toward that end.

Recommendations for Research

The present study points toward several fruitful venues for future research. First, and to the best of the authors' knowledge, this study is the first in the science education literature to investigate the influence of HOS courses on college students and preservice science teachers' NOS views. Further research is needed to establish the validity of the present findings and their generalizability to other contexts and NOS aspects. Such research is especially relevant given that the limited influence of the participant HOS courses on students' NOS views reported in this study is inconsistent with intuitive assumptions held by the science education community for a relatively extended period of time.

Second, the present study can only make claims regarding the influence of a single HOS course on students' NOS views. However, there might be some critical mass of HOS coursework that would substantially influence students' views of science. Future research studies could investigate the influence of completing multiple courses in HOS on students' conceptions of NOS. Such research can shed light on the practicality of recommending HOS coursework for the purpose of improving preservice science teachers' NOS views. Recommendations to add HOS coursework to an already extensive list of courses that preservice teachers have to complete might not be practical if it were found that a relatively large number of HOS courses is needed to substantially improve teachers' NOS views. However, if research indicates that a few HOS courses are significantly more effective in enhancing preservice teachers' views than a single course, then inclusion of such courses in science teacher preparation might be worthwhile.

Third, an interesting finding in the present study was that relatively more change was evident in the views of participants who entered the HOS courses with relatively more adequate NOS views. Moreover, the views of relatively more of these latter participants were enriched compared to participants who entered the courses with less adequate NOS views. This pattern was particularly pronounced in the case of preservice teachers. However, as was indicated earlier, this finding should be viewed with caution given the relatively small number of preservice teachers that were enrolled in the Evolution course. Nonetheless, the possibility remains that the present finding reflects a more generalized pattern. It should be fruitful to assess this pattern's generalizability in future research studies.

Fourth, should any collaborative efforts between science educators and historians of science to enhance students and science teachers' NOS views be initiated, accompanying research aimed at assessing the fruitfulness and effectiveness of such efforts would be in order. In particular, such research could focus on the influence of matching NOS aspects explicitly taught in the context of science and science education courses with those explored in depth in the context of HOS courses on enhancing learners' NOS views.

Finally, it was argued in the present study, that a form of NOS PCK might be needed to enable teachers to address NOS instructionally in their classrooms. It was also argued that HOS might serve as a source for the examples, analogies, metaphors, and stories related to the various aspects of NOS that would form the substance of such PCK. Research that investigates the possible effectiveness of the aforementioned collaborative efforts between science educators and historians of science in building teachers' NOS PCK might be a fruitful venue for future research.

Appendix A

NOS Questionnaire

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?
2. What is an experiment?
3. Does the development of scientific knowledge **require** experiments?
   - If yes, explain why. Give an example to defend your position.
   - If no, explain why. Give an example to defend your position.
4. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?
   - If you believe that scientific theories do not change, explain why. Defend your answer with examples.
   - If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples.
5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.
6. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence **do you think** scientists used to determine what an atom looks like?

7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence **do you think** scientists used to determine what a species is?
8. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
   - If yes, then at which stages of the investigations you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
   - If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.
9. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these **different conclusions** possible if scientists in both groups have access to and use the **same set of data** to derive their conclusions?

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